# GULF RESEARCH REPORTS

Vol. 6, No. 3
December 1979
ISSN: 0072–9027

GULF COAST RESEARCH LABORATORY
RESEARCH - SERVICE - EDUCATION
Since 1947
IN THE MARINE SCIENCES
Ocean Springs, Mississippi

*Published by the*
GULF COAST RESEARCH LABORATORY
Ocean Springs, Mississippi

# Gulf Research Reports

Volume 6 | Issue 3

January 1979


# Activities of the Gulf Coast Research Laboratory During Fiscal Year 1978-79: A Summary Report


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DOI: 10.18785/grr.0603.17

*Gulf Research Reports*, Vol. 6, No. 3, 317–339, 1979.

# ACTIVITIES OF THE GULF COAST RESEARCH LABORATORY DURING FISCAL YEAR 1978–79: A SUMMARY REPORT

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## ADMINISTRATION

Construction of a new facility, the Toxicology Building, was initiated and completed on the main campus of the Gulf Coast Research Laboratory (GCRL) during the year. The building design was based in part on the Environmental Protection Agency (EPA) Toxicology Laboratory, Gulf Breeze, Florida, and the Bionomic Toxicology Laboratory at Pensacola, Florida. The building, designed and constructed at a cost to the Laboratory of $230,000, contains about 3,700 sq. ft. on three levels, and provides separate areas for maintaining stock experimental animals, algal culturing, bioassaying and storage.

The Laboratory senior staff constitutes an advisory council that reviews toxicological research proposals, contributes to the experimental design and, when applicable, participates in the studies.

The annual operational budget consisted of $2,100,000 in State-appropriated funds, $1,140,226 in sponsored research and auxiliary funds, and $25,000 in Library Improvement Funds allocated by the 1978 State Legislature.

### *BOAT OPERATIONS*

The boats used to provide essential services include the 65-foot R/V GULF RESEARCHER, used in both the Laboratory's research and educational programs; the 38-foot steel trawler HERMES, used principally in the educational program; three diesel-powered cabin workboats; and some half-dozen Boston Whalers and other miscellaneous smaller craft powered by gasoline motors. The larger vessels are operated by six full-time boatmen, two of whom are licensed Masters for vessels of up to 100 gross tons. The Boston Whalers and other miscellaneous smaller boats are operated by scientists and technicians to meet the needs of some Laboratory research projects.

During the year ended June 30, 1979, R/V GULF RESEARCHER was at sea for 89 days and 39 nights. The HERMES spent 50 days at sea and the smaller boats made innumerable trips over the same period.

## RESEARCH

### *ANALYTICAL CHEMISTRY SECTION, Dr. Thomas F. Lytle, Head*

*Heavy Metals in St. Louis Bay* (Funded by E. I. duPont de Nemours & Company, Inc. [Du Pont]): Because heavy metals pose a potential threat to estuarine waters whether coastal areas are developed industrially or residentially, an assessment of heavy metals has been conducted in St. Louis Bay where very little of either type development exists. Heavy metals have been examined in as many ecological components of the bay as possible. Of primary concern to those interested in discharge limitations is the level of trace metals in the water column. This segment of the study, which gathered samples every two months for a year, was further divided into particulate and soluble heavy metals. To gain some perspective into the retention of heavy metals in the bay, sediments collected twice throughout the bay were also analyzed for heavy-metal content. An organism collection was designed based on the criteria that the species contribute significantly to the biomass of the bay, be it a resident species or of commercial importance. Depending upon the criteria met, either whole animals or edible portions were chosen for analyses.

The metals chosen for analysis were: copper, chromium, cobalt, nickel, zinc, cadmium, iron, titanium, vanadium, mercury, arsenic, selenium, antimony, strontium, molybdenum, beryllium, lead and also cyanide. All care was taken to avoid contamination in the collecting process, in sample preparation and in analysis. The only sample collection not totally successful was that of fish. However, oysters, clams and some fish species were found in adequate numbers to give some idea of heavy-metal content in the living segment of Bay St. Louis.

It had been hoped that the newly developed flameless techniques for atomic absorption could be used on all metals in the water samples. A great deal of time was devoted to adapting these techniques to the various matrices found in Bay St. Louis water. Though very sensitive and direct, flameless techniques at the present time are not suitable to apply to numerous metals in great numbers of samples of varying composition. Lack of reproducibility, tremendous analysis time, and cost indicated that these highly praised techniques are best used on single sample, single metal problems. At present, the analyses are being concluded, and a final report is in preparation.

*Nutrients in St. Louis Bay* (Funded by Du Pont): A sampling program was concluded in December 1978 to survey nutrients and other water-quality parameters in St. Louis Bay water to assess the distribution (laterally, vertically and temporally), source, and fate of these parameters. The choice of station locations was closely coordinated with other investigators at the Laboratory and associated projects

to maximize data usability. The parameters chosen for study were: orthophosphate, total phosphorus, nitrate, nitrite, ammonia, chloride, sulfate, suspended solids, turbidity, alkalinity, and silica. Samples collected for inorganic and organic carbon were forwarded to the GCRL Environmental Chemistry Section for analyses.

Most methods used in analysis, collection and sample handling were of EPA origin. Some methods required slight modifications to permit their application to coastal waters. At the present time, all analyses are complete and a comprehensive data report is in preparation. Included will be: comparison of 1978 data with water-quality data from as early as 1966; comparison with the Pascagoula River and Back Bay of Biloxi; intercorrelation of parameters; distribution as a function of salinity; proximity to proposed effluent sites; and season and trends within the phosphorus and nitrogen groups of nutrients.

*The Fate of Pollutants in Mississippi Sound* (Funded by Mississippi-Alabama Sea Grant Program [M-ASGP]): This is a cooperative study with the Environmental Chemistry Section. Its objectives are as follows: to document the present load of pollutants in the rivers and estuaries of Mississippi Sound; to gain a historical perspective of pollution in that area by vertically profiling the pollutants in the sediment column; to look at the distribution throughout the Sound as a function of sediment type and mobility; to assess the dangers of dredging in locales of high sediment pollution; to use key pollutants as indicators to trace pollutant movements; to educate the public to the current pollution situation in Mississippi Sound; and to gain a means of predicting impact on Mississippi Sound under a wide range of environmental conditions.

Since Pascagoula River is the most industrialized area along the coast, first efforts are being exerted there. This investigation is profiling the water quality in the Pascagoula River area. Included in the parameter list are: nitrate, nitrite, ammonia, orthophosphate, total phosphorus, suspended solids, turbidity, silica, phenols and Kjeldahl nitrogen. If phenol levels warrant, more sophisticated techniques will be developed to detect individual phenol components. Presently an attempt is being made to use phenolic aldehydes as tracers of paper mill waste movements. If successful, this will provide a certain degree of prediction in examining pollutant movements in rivers. All data will be used ultimately in helping the State and local governments develop proper land utilization plans for the coastal zone.

*BOTANY SECTION, Dr. Lionel N. Eleuterius, Head*

*Salt Marsh Vegetational Studies* (Funded by GCRL): Quantitative information is being accumulated on the relationship of marsh acreage versus open water in Davis Bay, a very productive estuarine system. In addition, the total area drained and amount of rainfall will be determined in this study of an entire estuarine ecosystem from the plant ecology viewpoint. A detailed vegetative map is being prepared as well as a map of the standing crop of all marshes surrounding Davis Bay. Vegetational structure of other Mississippi salt marshes is being determined. This study will reveal the vegetational and ecological attributes of a very productive estuarine system and may have far-reaching consequences.

*Populational Studies on Salt Marsh Species* (Funded by GCRL): This ongoing research is presently concentrated on the salt marsh rush *Juncus roemerianus*. Considerable population information has been gathered on the species and a portion of it is now in manuscript form. The ultimate goal is to document the distribution and the vegetative growth pattern of the major salt marsh species inhabiting the tidal marshes in Mississippi. Such populational studies are of considerable importance in relation to ecological work since ecotypes, single sexes, may dominate or compose large tracts of tidal marsh. Taxonomic work was also initiated as part of this study.

*Ecological Studies on Seagrasses and Salt Marsh Species* (Funded by GCRL): This work involves synecological studies where more than one species compose the vegetation. Included in this study is consideration of the hydraulic aspects of flooding various salt marsh zones done in cooperation with the Physical Oceanography Section. Grand Bayou, a high-salinity marsh dominated by *Juncus roemerianus* on Deer Island, Mississippi, has been tentatively selected for this portion of the study. Tidal inundation and discharge rates can easily be established because of the small, contained ecosystem represented in Grand Bayou. A paper on tidal inundation and exposure has been prepared and accepted for publication. Quantitative data on plant productivity and the nutritive discharge of detritus and other water-quality parameters will be assessed on the discharge and on the rising tide. The nutrients of Grand Bayou salt marshes in relation to flood and ebb tides and the flux of soil-water salinity have been determined and manuscripts are in preparation.

Studies of other ecological aspects of tidal marshes have been initiated. Biotic effects are also considered. Flowering phenology has been determined and a paper is in preparation. A graduate student completed thesis research on the response of the snail *Littorina* to the manipulation of salt marsh vegetation.

*Autecological Studies on Vascular Plants of Mississippi Salt Marshes* (Funded by GCRL): This project is essentially an extension of populational studies, in that ecological parameters such as soil nutrients, soil-water salinity, elevation, and other chemical and physical aspects of habitats (i.e., soil texture, evaporation), and the life history of the plant including germination are considered.

*Progeny and Genetic Studies on the Salt Marsh Rush, Juncus roemerianus* (Funded by GCRL): This work entails ongoing research begun several years ago. Plants have been grown from seed for several years to obtain Mendelian ratios, establishing the genetic mechanism responsible for the

sexual distribution found in this rush species. The work constitutes an effort to obtain basic information on this species which dominates Mississippi marshes. During the past year, controlled crosses between known parental types have been achieved and their seeds are presently being germinated. Hopefully, they will produce mature plants in less than the 2 years required under field conditions.

An apparatus has been constructed in the greenhouse that can extend or shorten the photoperiod exposure to induce flowering. Also, experiments have been conducted dealing with the physiological requirement of a cold period, known as vernalization, to induce flowering in this rush. If flowering can be induced, the growth and flowering cycle can be accelerated.

*An Illustrated Guide and Key to Salt Marsh Plants* (Funded by M-ASGP and GCRL): The purpose of this work is to prepare an illustrated guide and key to the salt marsh plants of Mississippi. It entails about 180 line drawings and scientific descriptions of local species of vascular plants. Keys to families, genera and species are being prepared.

*A Phytosociological Study of Horn and Petit Bois Islands* (Funded by National Park Service, U.S. Department of Interior): This work was completed in 1978, data analysis and the final report completed in early 1979. Phytosociological sampling was used to obtain information on community composition and successional patterns and interrelationships between the plant communities on these islands. Significant products resulting from the work were large format maps, produced in seven colors, that delineated the major vegetational features of Petit Bois and Horn islands. They will be of considerable value in the proper management of the islands and invaluable as baseline data for future scientific studies.

*St. Louis Bay – Botanical Survey and Plant Ecology of Salt Marshes and Submerged Meadows* (Funded by Du Pont): This work was completed in 1979 and the report is in the final stages of preparation. Vegetational mapping and community composition of salt marshes and submerged grass beds were documented. Standing crop, annual production and chemical characterization of indicator plants and associated soils were determined as part of a baseline environmental study.

*Physiological Studies on Salt Marsh Plants* (Funded by GCRL): Several experiments (cause and effect) were carried out in the greenhouse during fall, winter and spring. Modifications are needed to lower temperatures in the greenhouse before experiments can successfully be conducted during the summer. The effect of deficient nutrients, toxic levels of heavy metals, and the effects of different water levels have been determined. These data are presently being analyzed.

*Nutrient Enrichment Studies in Salt Marshes and Seagrass Beds* (Funded by GCRL): This project involves several field experiments utilizing fertilizer. One study was completed by a graduate student and a thesis prepared on the work. Another study entails nutrient loading of several different marsh types. The latter study has been in progress for several years and was previously a part of the general ecology studies described above. Two forms of nitrogen were applied to seagrass beds and the response observed. Further work is needed.

*Herbarium Collection of the Coastal, Estuarine and Marine Flora* (Funded by GCRL): The herbarium of the Botany Section presently houses about 20,000 specimens of plants. Most of the collections have been made locally since 1970, and probably compose the most thorough collection of plants found in the northern Gulf of Mexico. Most of the herbarium specimens have been identified but only a few have been mounted on herbarium sheets. The herbarium is presently being organized and specimens cataloged systematically. Duplicate specimens are exchanged with other herbaria throughout the United States, England, Europe, Australia and South America for collections of their coastal, marine and estuarine plant specimens. The herbarium serves as a teaching and research collection and currently includes spermatophytes, algae and fungi. Additional space is needed for an expansion of the herbarium.

*Tropic versus CONUS Military Materials and Equipment Evaluation Test* (Funded by U.S. Army): A new experimental study was initiated in the spring of 1979 to determine the effect of environmental factors on various military materials and equipment. This work is part of a nationwide military program.

*Studies on Plant Colonization on Dredge Spoil* (Funded by GCRL): A considerable amount of information was compiled over several years on plant colonization on dredged material. In addition, some information on plant succession has also been gathered. A more intense effort has recently been initiated because many years of observation have allowed insights otherwise unobtainable.

*Productivity and Decomposition Studies on Salt Marsh Plants* (Funded by GCRL): Several studies were completed on this aspect of salt marsh research. In addition to estimates of standing crop, two regeneration studies were concluded. Manuscripts have not been prepared on these projects, but the data have been analyzed. Assessment of decomposition was determined using nylon bags and new methods developed within the Botany Section. Further work is needed.

*ECOLOGY SECTION, Dr. Robert A. Woodmansee, Head*

*Phytoplankton Productivity in St. Louis Bay* (Funded by Du Pont and GCRL): Phytoplankton productivity is a fundamental community process of primary significance to the aquatic food chain. It is affected by a number of naturally occurring variables and is sensitive to a variety of unnatural environmental perturbations. The photosynthetic rate of phytoplankton is being measured at six locations in St. Louis Bay by both the dissolved oxygen and radioactive carbon techniques, and is being related to light intensity,

temperature, nutrients, chlorophyll, community composition and grazing pressure.

*Environmental Baseline Survey of St. Louis Bay: Benthic Study* (Funded by Du Pont and GCRL): Thirteen months of benthic infauna and epifauna collections were completed in December 1978 as part of the Laboratory's baseline environmental survey of St. Louis Bay. Benthic animals from these collections were identified and the data subjected to statistical analyses. The analyses, which included multilinear regression and cluster analysis, were done by the Laboratory's Computer Section, the data processing center at Texas A&M University, and the Ecology Section's minicomputer.

Monthly sampling for benthic infauna has been continued at the same locations during the first half of 1979. Specimens from these collections have been partially processed and stored at the Laboratory. Results of this continued study will be used in conjunction with the first year's work to investigate seasonal cycles and year-to-year changes in the benthic infauna of St. Louis Bay.

*Seasonal and Spatial Changes in the Macrobenthos of Simmons Bayou, Mississippi* (Funded by GCRL): Analysis of the results of the 1976–77 benthic study of Simmons Bayou was completed. This study showed the adverse effects of a dead-end canal on both benthic infauna and water quality. A paper reporting these findings, entitled "Macrobenthos of Simmons Bayou and an Adjoining Residential Canal," by James T. McBee and Walter T. Brehm has been accepted for publication in *Gulf Research Reports*.

*A Study of the Zooplankton and Floating Components of the Water Column from the Surface to 1,200 Meters at OTEC Sites in the Northern Gulf of Mexico and Eastern Caribbean Sea* (Funded by Department of Energy, Ocean Thermal Energy Conversion [OTEC] Program, Lawrence Berkeley Laboratory): A project to collect zooplankton and hydrographic data at possible OTEC sites in the Gulf of Mexico was initiated in June 1978. The current study is a continuation of the original contract which involved the collection and analyzation of zooplankton from an OTEC site south of Mobile, Alabama. It was expanded to include limited assistance with similar work at the Punta Tuna, Puerto Rico, OTEC site. Data are reported to the Lawrence Berkeley Laboratory, University of California. These data should provide the OTEC Program with some of the necessary biological data for proper design and environmental assessment of an offshore thermal energy conversion plant.

*ENVIRONMENTAL CHEMISTRY SECTION, Dr. Julia S. Lytle, Head*

*Development of High Resolution Glass Capillary Gas Chromatographic Analysis Coupled with Data System* (Funded by GCRL): Environmental pollution studies require constant updating and modification of accepted procedures to adequately deal with the complexity of separations and identifications of environmental pollutants. Recent improvements in gas chromatography demonstrated a need to make certain modifications to section procedures. Sample introduction into open tubular columns requires many special considerations that are not necessary for the larger packed columns. If the sample was to be introduced by the conventional microsyringe, the open, tubular glass capillary columns would be overloaded. To update section chromatographic capabilities, the Perkin-Elmer 3920 gas chromatograph was converted to accept glass capillary columns using a split injection method. This system has been interfaced with a Perkin-Elmer Sigma 10 data system using special programmed calculation procedures. The Sigma 10 is also equipped with basic, a powerful programming tool for calculations such as merging of data from several chromatographic runs, statistical analyses and automatic parameter updating for methods developed in the laboratory. This combination has proven to be the essential component necessary to investigate a wide variety of environmental pollutants with a high degree of credibility. In performing analyses of environmentally significant molecules present in trace levels, the analyst is constantly seeking to extend the range of analyses to lower and lower concentration levels with accurate mreasurement. Intensified research efforts by national and state governments have lead to intercalibration studies to assess the accuracy and precision of the data obtained.

*Petroleum Uptake by Marsh Plants* (Funded by GCRL): Field experiments were designed to study the uptake of petroleum by marsh plants and to establish phylogenetic ties through hydrocarbon synthesis. *Spartina alternifora, Juncus roemerianus* and *Scirpus robustus* stands were chosen for these studies. Three types of crude oil were placed around the root systems by routine innoculations into the sediment with a 100-ml syringe. After periods of 2 months and 6 months, tips of the plants were cut from each experimental plant and analyzed for high molecular weight hydrocarbons. Three separate experiments were carried out during different growth seasons, differentiating between maturation stages of individual plants. In each experiment, *Juncus roemerianus* absorbed crude oils into its tissue and *Spartina* and *Scirpus* did not. Not only did *Juncus* absorb petroleum hydrocarbons, but it produced almost equal amounts of alkenes and alkanes. Alkenes were almost absent in the other marsh plants. Biosynthesis of alkanes is not entirely understood and is even less understood for alkenes. By looking at various maturity stages in *Juncus*, insight has been gained into this biosynthesis. Some of the uptake experiments are presently being repeated and expanded to include uptake of naphthalene and octadecene, an aromatic and an alkene compound. It is possible that *Juncus* could serve not only as a contributor of food for estuarine nursery grounds but also act as a buffer and absorb hydrocarbons to lessen the effect of oil spills.

*The Fate of Organic Pollutants in Estuaries and Rivers Emptying into the Mississippi Sound* (Funded by M-ASGP and Du Pont): This study is a cooperative effort with the

Analytical Chemistry Section. The organic pollutants have been isolated and characterized; the trace metals and nutrients will be examined by the Analytical Chemistry Section. The object of the study thus far has been to document the hydrocarbon and total organic carbon levels in Bay St. Louis, Biloxi River and Bay, and the Pascagoula River system.

In view of ever-expanding development of the coastal zone, continuing pollution assessment is proposed to deal with the following issues of environmental concern:

1. The present conditions of Mississippi Sound and adjacent bays and rivers need careful documentation to determine just where emphasis should be placed in future monitoring efforts.
2. The sources of pollutants should be located and dispersal of pollutants documented. The mechanisms responsible for transport and deposition of pollutants in any area of the Sound must be known for various environmental conditions. Prediction of the fate of materials discharged into the Sound system may then be possible.
3. The public should be made aware of the present and future dangers of pollution to water resources of the state. Only an informed public will be willing to take action to prevent future detriment to the environment and insist upon clean-up procedures.
4. Guidelines for proper development of the coastal zone should be facilitated by a thorough knowledge of potential impacts of pollutants at any location in Mississippi Sound.

This study has two distinctly related areas of research. Trace metals to include such elements as copper, cadmium, zinc, nickel, manganese, silver, cobalt, lead and iron will be examined in all sample types used in the study. Their known toxic nature, stability and numerous sources warrant attention in any pollution study. Hopefully, the data gained here will also be useful in predicting the fate of radionuclides as well. Among the organic pollutants being studied are hydrocarbons which can result from petroleum pollution. Fatty acids and alcohols, not occurring extensively in petroleum, may be used as tracers of natural organics in the Sound, as well as providing additional information on the composition of organic constituents of sediments and water.

Both water samples (surface and bottom) and surface sediments were collected routinely at each sample site. Since trace metals and organics both are generally associated with fine-grain materials when in a nondissolved state, suspended material was examined separately from dissolved components and grain size analysis of sediments conducted. This may provide correlations to clarify sources of deposited pollutants and to assess the importance of suspended materials in transporting pollutants. Other studies have indicated the importance of trace metal-organic associations in water and sediments; therefore, this relationship will be examined as closely as possible. Where more appropriate, laboratory conditions will replace natural ones in trying to elucidate the character of this relationship.

*Studies of Chemical Constituents of Primitive Plants* (Funded by GCRL): Chemotaxonomic and geochemical studies are continuing on primitive plants. In the past, studies have been completed on ferns, mosses, fungi and lichens. The present study includes lilies, rushes, sedges and grasses. There are two purposes of the study. One purpose is to investigate the distribution of biosynthetically related compounds, hydrocarbons and fatty acids, relate them to a series of ancient plants, and determine what chemical changes took place in the evolution of plants. The other purpose is to establish hydrocarbon and fatty acid distribution patterns which can help in identifying natural source materials and their environments, and distinguishing them from pollutant sources.

*Sediment High Molecular Weight Hydrocarbons in Bay St. Louis* (Funded by Du Pont): During the past decade there has been an increasing concern over the possible effects of petroleum hydrocarbons in the marine environment. Because of this concern, a great amount of research is in progress on the biogeochemistry of these compounds. National agencies are initiating hydrocarbon baselines to be made on areas of potential oil pollution that would be subject to economical and environmental stress. With the building of a large Du Pont plant, it was determined that hydrocarbon baseline information was essential. To document present levels of hydrocarbons (aliphatic and aromatic) in St. Louis Bay, 13 stations were chosen for sediment studies to assess the hydrocarbon levels from the rivers and from known sites of possible hydrocarbon inputs, as well as correlate with other sediment studies made on the same stations. Sediments were collected during the first month of the study and hydrocarbon analyses made. These same stations were sampled during September, nine months after the first collection, and again analyzed.

In an effort to use hydrocarbon data to detect the presence of petroleum pollution, parameters have been derived from gas chromatographic data which can be used to indicate the presence of petroleum hydrocarbons. Thirteen of these parameters were measured in all sediments analyzed. Thus changes in these parameters can be detected by measuring the same parameters at any later time and can, therefore, establish both qualitatively and quantitatively the addition of petroleum influx to these sediments.

***FISHERIES MANAGEMENT SECTION,***
*Mr. William J. Demoran, Head*

*Oyster Resource Assessment and Monitoring Segment of the St. Louis Bay Baseline Survey* (Funded by Du Pont): This study involved the mapping of existing oyster reefs to determine their present condition as to productivity, natural mortality, spawning and setting, and predators with emphasis on the incidence of one known disease that affects oysters along the Gulf coast. Historical and recent salinity data were

analyzed to determine what effect they had on oyster growth in the Bay. The final report for this project is in preparation.

*A Survey and Assessment of Reef Shell Resources in the Mississippi Sound* (Funded by the Mississippi Mineral Resources Institute): This project involved locating and mapping deposits of ancient oyster shells buried under the floor of Mississippi Sound. The quantity of shell material was estimated and the value of this resource determined at current market prices.

*Oyster Resources Damage* (Funded by GCRL): Section personnel documented the damage to oyster resources caused by spring flooding from Pearl River and opening of the Bonnet Carré Spillway. The study provided the basis for the Bureau of Marine Resources' application for unmatched federal funds to rehabilitate the damaged oyster reefs. The Bureau received $600,000 in federal funds under Public Law 88–309, Section 4–B. Section personnel planned and supervised the oyster rehabilitation project. In addition, proper documentation of the resource damages made it possible for oystermen and oyster dealers to apply for and receive loans from the Small Business Administration at an interest rate of 7-3/8%.

*FISHERIES RESEARCH AND DEVELOPMENT SECTION, Dr. Thomas D. McIlwain, Head*

*ANADROMOUS FISHES:*

*Rearing and Stocking Striped Bass – Mississippi Gulf Coast* (Funded by National Marine Fisheries Service [NMFS], U.S. Fish and Wildlife Service and GCRL): The third segment of the project dealing with the rearing and stocking of striped bass was begun in September 1978. The objectives of this program were to establish, by rearing and stocking, a striped bass population in Biloxi Bay; to stock sea-run striped bass and determine their success; and to establish a source of fry from Mississippi brood fish.

Approximately 393,800 striped bass of South Carolina origin were stocked into Biloxi Bay. Some 56,700 of these fish were reared from eggs taken from Mississippi brood fish. The U.S. Fish and Wildlife Service provided 200,000 two-inch fingerlings from their hatchery at Meridian, Mississippi, and the remaining 193,800 were reared at GCRL from fry received from South Carolina.

All spawning of Mississippi brood fish was done at the Mississippi Game and Fish hatchery facility on the Ross Barnett Reservoir. Brood fish were collected from the Pearl River near Jackson, Mississippi, by Mississippi Game and Fish Commission personnel.

About 28,150 sea-run striped bass fingerlings were reared from fry provided by the State of Virginia. These fingerlings were stocked into the Bay of St. Louis.

A total of 258 striped bass stocked in previous years were returned to project personnel. Over 400 stripers, weighing from 3/4 to 5 pounds, were tagged with Floy T–Bar tags and released. Three tags have been returned. Returns indicate little movement, although with so little data, it would be dangerous to generalize.

A sampling program is in progress to check for natural reproduction of previously stocked bass and for occurrence of juvenile striped bass, to monitor previously stocked striped bass and continue assessing the results of all bass-stocking programs previously carried out in this area.

*Sport Fishing Analysis of St. Louis Bay* (Funded by Du Pont): Data collection for this project was completed in December 1978. The work entailed gathering data on total effort expended and total harvest of sport fish caught in St. Louis Bay. Data were gathered on species composition, seasonal and numerical abundance, as well as on size composition, method of capture, and catch per unit of effort. Data analysis is complete and a final report is in preparation.

*A Proposed Mississippi Marine Finfish (Selected) Fishery Management Plan* (Funded by M-ASGP): A management plan for selected Mississippi marine finfish was developed and adopted by the Mississippi Marine Conservation Commission (MMCC). This was a cooperative effort with the University of Southern Mississippi (USM). A working group comprised of personnel from GCRL, USM, MMCC and Sea Grant Advisory Service, held workshop sessions each month. The MMCC selected ten species for inclusion in the plan and appointed a 12-member advisory committee to provide input from recreation and commercial fishermen, processors and consumers.

*Description and Comparison of the Eggs, Larvae, and Young of the Yellow Bass, Morone mississippiensis, with Striped Bass, White Perch, and White Bass* (Funded by GCRL): Adult yellow bass have been collected in coastal Mississippi streams. Through temperature and photoperiod manipulation an attempt is being made to spawn these fish. The resulting eggs and larvae are being described and compared to the eggs and larvae of striped bass, white perch, and white bass.

*Food Habits and Feeding Selectivity of Larval Striped Bass under Intensive Culture Conditions* (Funded by GCRL): Several types of live foods, as well as several types of prepared dry diets, are being tested as food for larval striped bass being reared under intensive culture conditions. To date, the most effective food has been weed zooplankton. No prepared diets have proved satisfactory. This is the second year of a three-year project.

*COMMERCIAL AND RECREATIONAL FISHES:*

*Fishery Monitoring and Assessment* (Funded by NMFS and GCRL): The annual report for segment two of this project (October 1977–September 1979) was submitted on schedule. All scheduled monthly samples were collected and processed. Verified data were stored in the Laboratory computer. Selected analytical programs were used to write and publish reports on the relative abundance, size, growth,

and distribution of harvestable species each month.

Cooperative efforts continue to expand the fishery data base for use in achieving optimum production from Mississippi fishery resources through effective management planning and implementation. Information provided to the Mississippi Marine Conservation Commission (MMCC), Mississippi Marine Resources Council (MMRC), National Marine Fisheries Service, Gulf States Marine Fisheries Commission, Gulf of Mexico Fisheries Management Council (GMFMC), fishermen, fishery industries, and various other State and Federal agencies contributed to a progressively improved scientific basis for Mississippi marine fishery management.

Special shrimp sampling provided the MMCC with a scientific basis for seasonal and areal opening and closing of shrimp fishing seasons. The shrimp fishing community provided cooperative sampling effort with commercial fishing gear and boats. Several new areas in State waters were added to the established sampling program. Experimental and commercial sampling showed almost identical results. The Commission opened the season June 15, after examining predicted dates and considering economic and social factors. Continued monitoring was carried out after the season opened. Results indicated that predictions from the sampling program were accurate.

With the possible exception of croakers, all resources monitored in this project appear to be in good condition. Spotted seatrout and redfish provided good recreational catches and record volume of commercial redfish landings. A record catch of gulf menhaden was landed in 1978. Monitoring of juveniles indicated a good crop for 1979. Through June, the 1979 season Mississippi landings showed a 29% increase over 1978. There was little change in fishing effort.

Specimens collected in this project were provided to students and other agencies on request. The by-catch of the special shrimp sampling program was studied and, along with monitoring samples collected since the fishing season opened, will be researched for a master's thesis.

*Fisheries Planning* (Funded by GCRL, NMFS, MMCC and GMFMC): Active participation in fishery management planning activities of all concerned agencies in the Gulf of Mexico and several professional societies provided for effective input of Mississippi's interest in all Gulf of Mexico fishery management planning activities. Project personnel served in numerous important positions including chairmanship and membership in key committees.

*Environmental Baseline Survey of Bay St. Louis, Nektonic Macrofauna* (Funded by Du Pont): This segment of the multidisciplinary study of St. Louis Bay provided for collection and study of the nektonic fauna of the bay. Sampling was completed in December 1978 and all samples were collected on schedule. Laboratory processing was completed as originally scheduled. Verified data for all collections were stored in the GCRL computer. Data analyses were carried out during the remainder of the contract period.

*Environmental Baseline Survey of Bay St. Louis, Nektonic Macrofauna* (Funded by GCRL): This project is a continuation of the study initiated with Du Pont funding. The regular sampling program was carried out through June 1979, and is expected to continue through September. This will provide two full years of data and strengthen the baseline data base for management.

***ICHTHYOPLANKTON:***

*Cooperative Billfish Study* (Funded by M-ASGP and GCRL in cooperation with NMFS): Billfishes are important in sport and commercial fisheries of the Gulf region but little is known about their life history, biology, stock size or potential yield. Their larvae could provide a useful tool for estimating biomass and yield of adults, but the larvae of blue marlin, white marlin, and sailfish are difficult to separate from each other. This project initiated a study to resolve problems involved with identification of larvae of these three species from the Gulf of Mexico and adjacent areas in the Atlantic. Once the larvae of various billfish species can be identified, their abundance in the plankton can be determined and related to size of adult spawning stocks.

*The Role of Mississippi Sound in Recruitment to Sport and Commercial Fish Stocks* (Funded by M-ASGP and GCRL): Mississippi Sound, located within the "fertile fisheries crescent" in the northeastern Gulf of Mexico plays a potentially important role in recruitment to sport and commercial fish stocks. Understanding the interactions among fish spawning, early life history patterns, and the environment of Mississippi Sound can lead to predictive capabilities related to effects of alteration of circulation patterns and introduction of pollutants on recruitment success, and in turn provide useful information for management purposes.

This three-year study focuses on the pelagic early life stages of fishes, the most critical period in the life history of a species. It is during that period when year-class strengths and subsequent recruitment to fishable stocks are most likely determined. Objectives are to evaluate the importance of Mississippi Sound as a spawning and/or larval fish nursery area, to examine mechanisms of transport of fish eggs and larvae into and within estuarine nursery areas, to examine distribution patterns of pelagic young of important species, and to assess potential relationships between circulation patterns and survival of pelagic young and in turn future recruitment success.

*Larval Fish Collection* (Funded by GCRL): Work has begun to establish a good regional collection of identified larval fishes from the northern Gulf of Mexico. Increased recognition of the importance of knowledge of the early life history of fish has created a need to know and identify the early pelagic stages. The collection will be useful as a reference source to other researchers studying the early life of fishes in the northern Gulf. It will also be a source of material for studies of larval fish systematics as well as a teaching tool for graduate students interested in early life history research.

The major initial source of material will be collections presently available at GCRL, as well as those planned for the future. Additional sources are also being sought. Preliminary acquisitions include over 50 identified species or species groups.

*GEOLOGY SECTION, Dr. Ervin G. Otvos, Head*

*Offshore Barrier Island Study* (Funded by GCRL): This ongoing study is aimed at understanding the geologic history, genetic conditions, and present state of the six major Mississippi-Alabama barrier islands and the minor ones in Pelican Bay, Alabama. Three coreholes were drilled across Mississippi Sound in 1978, along a transect between Bayou la Batre area (Alabama) and western Dauphin Island. At the same time, two additional coreholes were drilled in the Sound near eastern Petit Bois Island. Dredge samples from bottom sediments of the western Mississippi Sound were obtained from several locations for analysis. The Mississippi National Guard provided periodic photographic coverage of certain island sections, allowing monitoring of changes over a short period of time. Monthly photographic reconnaissance flights over the Pelican Bay islands were also made during the spring-summer of 1979. Parts of the accumulated findings are being organized and processed for later presentation at professional meetings and for publication.

*Santa Rosa Island and Sound* (Funded by GCRL): Study of the island, its lagoon and adjacent bays continued with granulometric and micropaleontological analyses of drill core material provided by the U.S. Army Corps of Engineers, testing laboratories and GCRL drillings. Complete sediment sequences of 15 coreholes from Santa Rosa Sound were provided by the Corps, while the Section drilled an additional 15 shallow coreholes on the island and adjacent mainland areas. Comparison between this island and the Alabama-Mississippi barrier islands has major significance in understanding their formation and development conditions, as well as the Holocene evolution of the whole northeastern Gulf coastal zone.

*Origins of Lake Pontchartrain and Surrounding Holocene Areas* (Funded by GCRL): The organization of available research material was concluded and some of the results presented at the fall 1978 meeting of the Gulf Coast Association of Geological Societies. Two papers have also been published on the subject.

*Holocene Geology of Hancock County Marshland* (Funded by GCRL): Earlier obtained research material was organized; it provided the basis for a paper, prepared in conjunction with the Botany Section, for publication in *SIDA Contributions to Botany*.

*Pleistocene Stratigraphy of Hancock County* (Funded by GCRL): Detailed study continued of field samples and earlier drill material. New core material from four drillholes on the National Space Technology Laboratories site was obtained from the U.S. Army Corps of Engineers. Five additional coreholes were drilled by the Geology Section. The research is aimed mainly at establishing the influence of late Pleistocene marine transgressions in the Hancock County area.

*Pleistocene Development in Southeastern Louisiana* (Funded by GCRL): Field and laboratory work continued. Research results from the fossil-rich Tunica Hills (Mississippi-Louisiana) creek terrace sequence have been prepared and accepted for publication in *Quaternary Research*.

*Beach Sand Analysis* (Funded by GCRL): Granulometric analyses were performed on numerous samples and a report on the results was provided to the Physical Oceanography Section.

*Sound Sediment Granulometry* (Funded by GCRL): Granulometric analyses, related to various oyster reef areas, were performed on samples for the Fisheries Management Section. Samples were also processed for the Oyster Biology Section.

*St. Louis Bay* (Funded by Du Pont): Monthly sediment analyses of collected Bay samples were performed on this project. Numerous additional samples were analyzed from various marsh areas along the northern Bay shores for the Botany Section. A report on the project has been submitted. After completion of the Du Pont project, sample analyses continued on a monthly basis for GCRL.

*MICROBIOLOGY SECTION, Dr. David W. Cook, Head*

*Viral Evaluation of Prohibited Oyster Growing Waters* (Funded by M-ASGP): This joint project with the University of Southern Mississippi is designed to assess the relationship between numbers of pollution-indicator bacteria in the water and the level of viruses found in oysters. GCRL is responsible for water- and oyster-sample collections and bacteriological analysis. Data produced will be available to State and Federal regulatory agencies for use in assessing present-day water quality standards.

*Environmental Baseline Survey of St. Louis Bay: Microbiological Investigations* (Funded by Du Pont): Water samples from 14 stations in the Bay and adjacent rivers are being collected at 2-week intervals and analyzed for coliforms and fecal coliforms. These data will document the present-day levels of sewage pollution in the Bay. Each month, water samples collected at 22 stations are analyzed for microbial biomass using adenosine triphosphate (ATP) methodology. These data will be correlated with phytoplankton counts and productivity measurements.

Populations of selected groups of bacteria are being studied in sediments from seven locations around the Bay. Metabolic activity rates and total biomass are being determined.

*Environmental Baseline Survey of St. Louis Bay: Pesticide Analysis* (Funded by Du Pont): In this project, continued from last year, water samples were collected bimonthly from eight stations, sediment samples bimonthly from 11 stations, and oyster samples quarterly from two stations within St. Louis Bay. All samples were extracted and are currently being analyzed by gas chromatographic methods for

chlorinated hydrocarbon insecticides and polychlorinated biphenyls.

***Steam Unit to Aid in Oyster Shucking. Part II. Microbial and Organoleptic Tests of Oysters Exposed to Steam*** (Funded by MMRC): When oysters are exposed to moderate temperatures, the adducter muscle relaxes, making the oyster easier to open. Investigations were carried out in cooperation with an oyster processor to determine if the heating process affected the microbiological or organoleptic quality of the oyster. Evaluations of the treatment on drip loss and shelf life of shucked oysters were also made.

***A Study of the Genus Bacillus in Marine and Estuarine Sediments*** (Funded by GCRL): Monthly sampling of sediments from St. Louis Bay has continued to yield large numbers of *Bacillus.* Over 1,000 cultures have been collected and are being identified in order to better understand the distribution, taxonomy and ecology of the genus *Bacillus* in estuarine sediments.

***Toxicity Testing: Inter-laboratory Comparison with Marine Animals*** (Funded by EPA): In conjunction with three contract and two EPA laboratories, GCRL conducted static and flow-through bioassay evaluations for the toxins silver and endosulfan against sheepshead minnows (*Cyprinodon variegatus*), possum shrimp (*Mysidopsis bahia*), and the copepod *Acartia tonsa.* These tests were conducted so that the EPA might gain insight into the expected similarity (or dissimilarity) of data as a function of the performing laboratory. Data generated thus far indicate that the static 96-hour $LC_{50}$ of endosulfan to *C. variegatus* is 2.2 ppb and to *M. bahia* 1.0 ppb. The static 96-hour $LC_{50}$ of silver to *M. bahia* was 176 ppb. Under dynamic conditions, endosulfan reflected a 96-hour $LC_{50}$ of 0.84 ppb to *C. variegatus.*

***Effluent Toxicity Evaluation: First Chemical Corporation*** (Funded by First Chemical Corporation): GCRL has contracted with First Chemical to perform flow-through bioassay tests using the discharge effluent from its Pascagoula, Mississippi, plant. Test species are sheepshead minnows (*Cyprinodon variegatus*) and possum shrimp (*Mysidopsis almyra*). These tests will be conducted quarterly for one year. First-quarter results indicate that for sheepshead minnows, effluent concentrations less than or equal to 90% produced no mortality. For the mysids, mortalities at effluent concentrations less than 75% were not different from the controls. The biochemical oxygen demand, total inorganic and organic carbon, phenols, suspended solids, and total chromium analyses are being determined by the Microbiology, Environmental Chemistry, and Analytical Chemistry sections of GCRL as part of this contract.

*MICROSCOPY SECTION, Dr. William E. Hawkins, Head*

***Studies on Intracellular Parasites and Tissue Responses in Oysters*** (Funded by M-ASGP and GCRL): These studies continued for the second year. Oysters are being provided by the GCRL staff and the Food and Drug Administration Shellfish Sanitation Laboratory at Dauphin Island, Alabama. The oysters are being surveyed with light and electron microscopy for intracellular parasites. These parasites are found in inclusion bodies in the digestive gland. In addition, the incidences of inflammatory and hyperplastic lesions are being compared in oysters taken from various locations. The oyster may prove to be a useful indicator organism if a relationship is found between these cellular changes and certain environmental factors.

***Histological and Cytological Investigations of Various Organs and Tissues of the Atlantic Croaker*** (Funded by GCRL): This study is in its second phase which consists of preparation of an atlas of normal croaker histology and cytology. Croaker organs and tissues have been processed, sectioned, and photographed. The results of this study will provide a basis for determining pathological changes that might result from exposure to various toxicants.

***Studies on Histopathological Effects of Heavy Metals on Marine Fish*** (Funded by GCRL): Studies are continuing on the effects of cadmium on tissues of the spot *Leiostomus xanthurus.* Initial efforts were aimed at determining the normal ultrastructure of the kidney and gills of these fish. In these studies, both transmission and scanning electron microscopy have been utilized. It was determined that after a 48-hour exposure of spot tissue to cadmium, the metal accumulated mainly in abdominal viscera and caused severe damage to proximal tubule cells in the kidney.

*OYSTER BIOLOGY SECTION, Dr. Edwin W. Cake, Jr., Head*

***Oyster Depuration in Mississippi: Engineering Assessments*** (Funded by M-ASGP and GCRL): The second phase of a 3-year study was completed. The study involved a sanitary engineering analysis of a small, pilot-scale, oyster depuration facility operated by the Oyster Biology Section at Point Cadet in Biloxi, Mississippi. Results indicated that water degradation in both open and closed depuration systems was not significant with regard to acceptable levels for waste discharged into receiving waters. In addition, the following conclusions were reached: solids generated during depuration can be removed via conventional gravimetric means; ozoniation provided adequate disinfection and reduced degradation of the process water; ozoniation will reduce or eliminate the need for wastewater treatment prior to discharge; and closed depuration systems can be operated for extended periods without significant problems and will function adequately in an open mode of operation.

***Enhancement of Oyster Production in a Tidal Lagoon in a U.S. Park Service Wilderness Area, Horn Island, MS.*** (Funded by GCRL): Study participants are attempting to increase the production of oysters in a wilderness lagoon via natural methods including branch culture, shell relaying, and the introduction of brood stocks from nearby island lagoons. All aspects of the study are being conducted with natural materials and without mechanical or motorized equipment as per wilderness guidelines. This is the first year of a two-year study in cooperation with the Gulf Islands National Seashore.

*Population Dynamics of Selected Oyster Populations in Mississippi Sound and Adjacent Waters* (Funded by Mississippi Bureau of Marine Resources [MBMR] and GCRL): A one-year monitoring program was begun on five of Mississippi's commercial oyster reefs to determine rates of spatfall, growth, natural and unnatural mortality, and the prevalence of oyster pathogens and predators. The study should be the forerunner of an extensive monitoring program for all reefs to produce data needed for proper management of the State's oyster resources.

*Development of an Oyster Management Model Applicable to the Mississippi Oyster Fishery* (Funded by MBMR and GCRL): During this one-year study the Oyster Biology and Fisheries Management section staffs will acquire and evaluate existing oyster production models for applicability to the Mississippi Sound oyster industry. They will attempt to determine the technical information inputs required to operate such a model and suggest modifications so that the selected model will apply to the State's situation. Data from the monitoring study (see previous project) may be utilized to manipulate the chosen model.

*Oyster Depuration in Mississippi: An Evaluation of Off-bottom Relaying for Cleansing Oysters* (Funded by GCRL): The first year was completed of a two-year study to compare "offbottom, containerized" relaying with depuration and traditional "onbottom" relaying. Initial results indicated that polluted oysters held in plastic chicken coops cleansed sufficiently within the widely accepted 15-day "relaying" period. The second year of the study will concentrate on system analysis and modification to design the best containerized alternative to onshore depuration and onbottom relaying.

*Oyster Mariculture in Mississippi: Seed Oyster Hatchery Operation and Testing* (Funded by GCRL): Current experimental oyster mariculture research at the Oyster Biology Research Facility of GCRL at Pt. Cadet, Biloxi, MS, includes, but is not limited to the following projects: seed oyster production (hatchery production); experimental raceway and tank culture of hatchery-reared seed oysters; evaluation of new cultch materials for hatchery-reared seed oysters; operational monitoring and utilization of a low-cost and low-energy greenhouse for oyster culture; design and testing of windmills for pumping and circulating water in mariculture systems; optimization of natural setting versus wild setting; and the feasibility of utilizing natural spatfall to increase seed production using Maheo and shell spat collectors.

*Oyster Mariculture in Mississippi: Field Tests with Hatchery-Reared Seed Oysters* (Funded by GCRL): These ongoing studies involve the utilization of seed from the GCRL hatchery in various student and staff research including: growth and survival of seed oysters in Mississippi Sound and adjacent waters; and nursery and field techniques for handling spat and seed oysters in the wild.

*PARASITOLOGY SECTION, Dr. Robin M. Overstreet, Head*

*Commercial Fishes of Mississippi: Spawning and Miscellaneous Biological Parameters* (Funded by NMFS and GCRL): The first of two tasks in this project was to determine the season of spawning, size of spawning fish, fecundity, and other aspects of reproduction for the spotted seatrout and red drum in Mississippi. The second task involved evaluating specific aspects of migration, feeding, growth, and health of a variety of commercial finfishes and shellfishes.

*Digenea from Marine Fishes of the Northern Red Sea* (Funded by the Israel Academy of Sciences and Humanities): This long-term project will ultimately produce a monograph on piscine adult digeneans of Red Sea fishes for the *Fauna Palaestina* series. Many specimens already have been collected and more are expected within the next three years. Simultaneous work also is being conducted on other parasites of Israeli fishes, some of which have been implicated in diseases of humans that consume the fish and of fish that are reared commercially.

*Pathological Effects of Larval Thynnascaris Nematodes in the Rhesus Monkey (Macaca mulatta)* (Funded by the U.S. Air Force): The primary purpose of the study is to determine the pathological alterations in the alimentary tract of monkeys that have been administered one of the common local larval nematodes.

*Studies of Parasites of the Northern Gulf of Mexico Region* (Funded by GCRL): Several studies are underway dealing with various different parasitic organisms. These studies deal with the taxonomy, systematics, anatomy, life histories, pathological effects, and control of the organisms. Some of these parasites have been implicated in harm to commercial and recreational fishes. These organisms include microbes, protozoans, metazoans, and even the hosts and potential hosts for the organisms.

*Experimental Organism Culture Group* (Funded by GCRL): In early 1979, the culture-holding group of the Parasitology Section moved part of its operation into the front section of the new Toxicology Building on the Laboratory's main campus. The purpose of this group is to develop techniques for culturing various freshwater and marine organisms and to supply these organisms to various sections and other State institutions for use in experiments, primarily toxicity testing and parasitological life-cycle studies.

Presently, several species of fishes, algae, copepods, amphipods, and other species are being reared. The facilities include those necessary for algal culturing, spawning fish, and holding fishes and invertebrates.

*Toxicity Testing: Inter-Laboratory Comparison with Marine Animals* (Funded by EPA): This study was conducted in cooperation with the Microbiology Section (see page 324).

*Effluent Toxicity Evaluation* (Funded by First Chemical Corporation): This study was conducted in cooperation with the Microbiology Section (see page 324).

*Life Cycle Stages of Cyprinodon variegatus to Philadelphia Academy of Sciences for Toxicity Testing* (Funded by Philadelphia Academy of Sciences): Eggs, 2-day old larvae, 28-day old juveniles, and adults are being cultured for tests to be conducted by Scott Paper Company of Alabama.

*PHYSICAL OCEANOGRAPHY SECTION,*
*Mr. Charles K. Eleuterius, Head*

*Hydrographical–Meteorological Atlas of Mississippi Sound* (Funded by M-ASGP): Mississippi Sound is one of the most productive estuaries in the world. Results of studies on the hydrography and meteorology of Mississippi Sound and adjacent areas appear in numerous documents. Planners, management authorities, educators, laymen and scientists are confronted with investing considerable time in a review of the literature to obtain fundamental information on the area. Information on the physical-chemical characteristics of Mississippi Sound does not exist at present. A single volume summarizing present knowledge would be a valuable reference.

This research to develop such a reference source involves extensive statistical analysis of existing sets of hydrographic data to determine characteristic seasonal levels and spatial distributions of physical-chemical parameters: pH, temperature, salinity, dissolved oxygen and density. Statistical measures of central tendency and variability of each parameter at four depths will be shown in the form of isopleth charts. Some of the more informative results of remote sensing studies of Mississippi Sound conducted by the Earth Resources Laboratory, National Aeronautics and Space Administration, will be included; also, summarized information on hurricanes, wind, rainfall, air temperature, wave climate, rivers, and physiography of the basin. It is expected that the atlas will go to press by December 1979.

*Hydrology of St. Louis Bay* (Funded by Du Pont): The water quality of an estuary is dependent upon the character of the waters received and the residence time of waters within the basin. The transport of dissolved or suspended materials, pollutants included, is almost wholly dependent upon the natural circulation of waters. Anomalous perturbations in levels of physical and chemical parameters are only detectable if a baseline or norm has been established.

The objective of the hydrological study of St. Louis Bay was the development of a baseline of hydrographic parameters to serve as an estimate for "normal" conditions. The hydrologic data-collection effort, which was coordinated with the other disciplines participating in the environmental baseline study, obtained measurements of water temperature, salinity, pH, dissolved oxygen, turbidity (depth of extinction of visible light), water color, and currents. In addition, fixed and automated sampling platforms continuously recorded wind speed and direction, water elevations, water temperature, pH, dissolved oxygen and salinity.

Analyses of these data provided information on the vertical structure of the water column, influence of river flows, circulation patterns, and seasonal trends in the levels of the physical-chemical parameters. This study was the first major investigation of the hydrology of St. Louis Bay. When released, results of the study should prove valuable in the management of this complex estuarine subsystem.

*Numerical Model of St. Louis Bay Circulation* (Funded by Du Pont): Essential to ascertaining the fate of dissolved or suspended materials in an estuary is an understanding of the natural circulation of the basin waters. A finite-difference numerical model based on the hydrodynamic equations of motion and continuity was applied to St. Louis Bay. The model, which allows for the flooding and subsidence of waters from land areas, accommodates wind stress and includes a quadratic form of bed resistance. A 30-second time step was used to provide the necessary spatial resolution to properly represent the basin geometry and current regime.

The model was tested initially using a simple sine wave as input, then later with the prescribed tidal conditions. Model graphic output consists of computer-generated hydrographs of water elevation and current vector diagrams. Initial test results agreed well with current measurements from the 13 hydrographic surveys conducted in St. Louis Bay. Testing of the algorithms for wind stress and river flow will be done prior to final production runs. The model will be a valuable investigative tool for future investigations of St. Louis Bay.

*Hydrology of Mississippi Sound North of Petit Bois Pass* (Funded by MMRC): To properly manage the Mississippi Sound estuary, it is important to know the spatial and temporal variability of certain physical-chemical parameters. Previously acquired hydrographic data were analyzed to determine mean levels of water temperature, salinity, pH, dissolved oxygen, nitrite-nitrogen, nitrate-nitrogen, orthophosphate and total phosphate. These seasonal mean levels were displayed in depth-composited isopleth charts. In addition, the statistical distribution of each parameter for each cruise was graphically displayed. The results of this study provided a hydrographic characterization of a previously little studied area of Mississippi Sound.

*Development of a Plan for the Exploration of Mississippi's Marine Mineral Resources* (Funded by Mississippi Mineral Resources Institute): The judicious exploration and assessment of mineral resources in Mississippi's coastal lands, marine waters, and earth beneath the waters of the estuaries and adjacent continental shelf, require that a plan of study be prepared. This plan, developed in consultation with a geological oceanographer and a geophysicist, and with input from staff members of several Mississippi universities, is intended to eliminate duplication, establish research priorities and promote cooperation among research participants.

Emphasis has been placed on combining sampling where technically and economically feasible. The plan also includes research to ascertain the environmental impact expected in the event a particular mineral resource is developed.

The plan is expected to be completed by October 1979.

*Characterization of Tidal Bayous and Development of Statistical Evaluation/Monitoring Techniques* (Funded by GCRL): This study involves analysis of four years of almost daily measurements. Baseline conditions on a number of physical-chemical parameters are being established that will assist in recognizing anomalous events when they occur. Monitoring techniques based on multidimensional graphics are being explored as a practical tool for management authorities. Characterization of the tidal bayou by both chemical and physical constituents will be accomplished as part of this study.

*Determination of Fundamental Factors Affecting the Hydrodynamics and Ecology of Mississippi Sound* (Funded by GCRL): This study is actually an aggregate of investigations that have provided much specific information on Mississippi Sound. The results have been fundamental to furthering an understanding of the hydrodynamics and ecology of the estuarine basin.

Information such as the volume of water, area of the air-sea interface, statistical distribution of depths, classification of Mississippi Sound as to estuary type, geographical definition of Mississippi Sound, and fundamental period of oscillation, have been determined under this broad study. Recently, cross-sectional areas of the passes into Mississippi Sound were determined by a bathymetric survey. Presently, emphasis is on determining the frequency and cause of low-oxygen waters in Mississippi Sound. In addition, vertical gradients in temperature and salinity are being investigated.

The results of all the investigations grouped under this one research caption are providing fundamental information required to address hydrodynamically related problems. Until these fundamental factors are provided, complicated hydrodynamic questions cannot be answered.

#### *PHYSIOLOGY SECTION, Dr. A. Venkataramiah, Head*

*Seasonal Variations in Glycogen, Total Fat, and Caloric Energies of the American Oyster in the Mississippi Sound* (Funded by GCRL): Oyster quality was determined in the past on the basis of glycogen content. The present studies were undertaken to relate oyster (*Crassostrea virginica* Gmelin) quality to seasonal changes in lipids which contribute more to the caloric content. The total lipid and glycogen contents were found to undergo a significant seasonal change in relation to size and sex. Glycogen content was low in July and October, and high in February. Fat content was low in October and high in April. The caloric content of oyster meat decreased in the following order: April, February, July and October. Among the lipid classes, free sterol fraction has yielded the highest calorific energy in both "lean" (October) and "fat" (February) oysters. Phospholipids from lean oysters yielded more calories than from fat oysters. Variations in caloric content seem related to the degree of unsaturation of lipid class.

*Seasonal and Emperical Predictions of Meat Growth in Reef Oysters from the Mississippi Sound* (Funded by GCRL): The relationship between shell length and meat weight is used to set minimum-size limits for the harvest of some bivalves. Considerable attention has been paid to this problem in other species of bivalves but not in oysters from Mississippi Sound. Therefore, experiments were made to propose predictive models to describe the relationship between meat weight versus shell length on a seasonal basis. Males and females exhibited a polynomial increase in meat weight as shell length increased. Growth rates of the reef population, as computed from the models, suggest that oyster meats increase in weight from October to April and decrease from April to October. Males seem to lose their weight for a longer duration than females. Meat weight per unit length revealed variations in the oysters. Small males (30 mm) were heavier from July to October, while females of the same size were heavier from October to April.

*Effects of Starvation and of Algal Feeding on the Tissue Cholesterol Levels in Penaeid Shrimp* (Funded by GCRL): Tissue lipid and cholesterol contents of brown shrimp *Penaeus aztecus* Ives were compared in the laboratory among starved individuals and those fed green algae *Ulva lactuta* and *Enteromorpha* sp. or a pelleted diet. Cholesterol levels seem to vary with size of the shrimp, sex and diet. Shrimp fed a pelleted diet showed an increase in cholesterol content with increased body weight. Females showed a higher cholesterol content in certain tissues than males fed on the same diet. Muscle cholesterol increased linearly with body weight in females, while it was not size-related in males. Starvation did not alter the cholesterol level except in hepatopancreatic tissue. The cholesterol level decreased significantly in shrimp fed on green algae. Extrapolating these results, it was suggested that the bulk of marketable shrimp (60-68 count per pound) have relatively lower levels of cholesterol than was reported in nutritional and medical literature. "Jumbo" shrimp (30 or less count per pound) showed a value close to the reported value. Compared to caviar, organ meats, and eggs, shrimp muscle showed a low cholesterol content.

*Toxicity and Impingement-Entrainment Studies (Phase I) for Ocean Thermal Energy Conversion (OTEC) Plants* (Funded by Department of Energy [DOE]): In proposed OTEC plants, solar thermal energy of the tropical oceanic surface waters can be converted into electric energy. The energy conversion is accomplished by evaporating ammonia in heat exchangers with the help of thermal energy from the surface water. The vapor drives a turbine attached to an electric generator and the exhaust gas from the turbine is condensed to liquid ammonia with cold water drawn from depths of 2,000 feet or more which is then pumped back to the evaporator.

The problem areas in this technology are: (a) corrosion of heat-exchanger metals; (b) leakage of ammonia into seawater from heat exchangers; and (c) continuous dosing of chlorine into the system to clean the heat exchangers of biofouling and chlorine discharge into seawater. These

components used in OTEC plants have been known to be toxic to marine plants and animals.

The DOE contracted with the Laboratory to study the toxic effects of the three components as well as their synergistic effects on: (a) a commercially important marine fish, and (b) a biologically important species in the marine food cycle. On the basis of findings, recommendations will be made to the DOE concerning lethal levels, incipient lethal levels (beyond which 50% of the test animals will not survive for 96 hours), and sublethal levels of each component to the selected marine animals. Also the DOE will be advised concerning chlorine dosage levels in OTEC plants. Since September 1, 1978, the following conclusions have been made:

A. Mullet (which spawn in offshore waters) and marine copepods (whichever are available in large numbers) or sargassum shrimp were collected as experimental animals. If time permits, both copepods and shrimp will be tested.

B. An experiment was carried out to find out if starvation during bioassay would affect the behavior and survival of test animals. In mullets, no such effect was observed during the 96- and 144-hour bioassay periods.

C. An experiment was carried out to determine the salinity tolerance range of mullet. Mullet (4 to 6 inches) could withstand a 1 to 40 parts per thousand (ppt) salinity range when transferred from a control of 20 ppt. This information permits testing mullet in a common test salinity to which they have been acclimated slowly from their habitat salinity.

D. Collection and maintenance techniques of mullet in the laboratory have been established. After some initial problems, marine copepods and sargassum shrimp were held fairly well for about 2 months.

E. Although bioassay techniques with aluminum and ammonia are fairly well established in other laboratories, chlorine chemistry in seawater is not well understood. It is only in recent years that this line of research has attracted the attention of power-plant operators. The experimental results published from other laboratories raised more questions than provided answers. Therefore, the following tests were made in the laboratory to understand chlorine behavior and standardize techniques for bioassay.

1. Chlorine demand was determined in unconditioned, deionized water (unconditioned water is free from animal contact or their wastes) versus unconditioned seawater. The seawater exhibited a chlorine demand, compared to no appreciable demand in deionized water.

2. Chlorine demand was compared between unconditioned seawater and conditioned seawater. For conditioning the water, mullet, or any one of the experimental species, can be kept in it for varying periods of time and would secrete ammonia or other metabolic wastes. The conditioned water has shown more chlorine demand than unconditioned water.

3. Chlorine demand was determined in relation to 6, 12, 18 and 24 hours of conditioning in seawater. The chlorine demand increased directly in proportion to the increased conditioning periods with the highest in 24 hours and the lowest in 6 hours.

4. Chlorine demand was determined in relation to the volume of conditioned test media by holding ten fish in each of 5, 10, 15 and 20 gallons of media. It was found that the smaller the volume, the higher the chlorine demand, and vice versa. This is due to the presence in a smaller body of water of higher concentrations of ammonia with which chlorine possibly combines to form some kind of chloramine.

5. Chlorine demand was determined in relation to biomass by holding test animals having volumes of 122 and 152 grams in 20-gallon tanks. A greater amount of chlorine was lost, as expected, in tanks with 122 grams volume than with 152. The loss was attributed to the presence of a lower ammonia level, 0.53 ppm, in the tank with 122 grams of fish in comparison to 0.62 ppm in the second tank.

Bioassay studies with ammonia are near completion and studies with chlorine are in progress. Based on the data, lethal, incipient lethal, and sublethal levels of ammonia for mullet and sargassum shrimp were identified.

*SYSTEMATIC ZOOLOGY SECTION, Mr. C. E. Dawson, Head*

***Systematic Studies on Fishes of the Families Microdesmidae, Dactyloscopidae and Syngnathidae*** (Funded by the National Science Foundation): Systematic studies continued on fishes of the families Microdesmidae, Dactyloscopidae and Syngnathidae. Review studies on the pipefish genus *Nannocampus* and the polytypic species *Oostethus brachyurus* were completed. Descriptions of several new or little-known Atlantic and Indo-Pacific pipefishes were completed. In addition, a manuscript treating 6 genera and 29 species of American pipefishes was all but completed during this period. In connection with these tasks and other current problems, studies were conducted on these types and other fishes in a number of museums in the United States, Europe, Australia, and New Zealand.

## SPECIAL FACILITIES

*MARINE EDUCATION CENTER, Mr. Gerald C. Corcoran, Curator*

Visits to the Center increased again this year, from 30,155 to 32,754. The increase was not as great as in previous years, which is an indication that the present facility is fast reaching the maximum number of visitors that can be accommodated.

The Curator assisted with a workshop for minority teachers and exceptional high school students on the Gulf Park campus of the University of Southern Mississippi. His presentation centered around the adaptation of saltwater techniques to studies of freshwater animals. Most of the 100 participants were from schools located far from the coast.

The continuing education program designed for teachers had a total of 30 students enrolled during the year, 20 of whom were teachers. "Basic Techniques in Marine Science for Teachers" was the only course offered at the Center during this time.

The student intern program was discontinued this year. In its place a volunteer summer program was initiated. Four students from the seventh through ninth grades assisted in the care and feeding of the exhibited animals and thus were informally introduced to local marine and freshwater species. A similar program is planned for FY 80.

As in past years, the Creative Learning in Unusual Environments (CLUE) groups from Memphis, TN, visited the Center, with a total of six groups participating. Arrangements were made for staff supervision of daytime and nighttime seining on the beach, a boat tour of Biloxi harbor, a visit to Marine Life of Gulfport and a visit to the Center. The Whitehaven Methodist Day School also took advantage of those arrangements for a visit.

A radio program on sharks was presented on Station WGCM, Gulfport. In addition, the Curator appeared on Station WLOX–TV, Biloxi, on 11 different occasions and presented slide programs on local wildflowers, crabs, saltwater fish, freshwater fish and other marine subjects. A weekly program has been suggested.

Personnel at the Center continue to act as consultants to Marine Life of Gulfport on problems of water quality and diseases of marine animals. The same service is offered to local pet shops and individuals. Information on how to start and maintain marine aquariums is provided upon request.

Color slides of poisonous and nonpoisonous snakes of the area were provided for educational purposes to Howard Memorial Hospital of Biloxi and a hospital in New Orleans. The Center was requested to have copies of the slides made that might be retained by the hospitals and used in their continuing education program. Center personnel continue to be called on to identify local snakes for area hospitals providing treatment to snake-bite victims.

Two new publications have been generated at the Center: "Banded Coral Shrimp" and a "Fun Book" for the elementary grades. The coral shrimp pamphlet notes that this animal was first reported from Mississippi waters since establishment of artificial reefs. The "Fun Book" is a coloring book featuring local animals.

### *THE GUNTER LIBRARY, Mr. Malcolm S. Ware, Senior Librarian*

Statistics on the number of persons using the Gunter Library were kept during this year for the first time and the average was found to be 70 per working day.

A total of 257 standing orders were maintained for journals and serials. Three new exchanges of publications were established, and 10 new subscriptions were opened. Back numbers for 35 journal runs were purchased, and 377 volumes were bound.

Significant additions were made to the journal collection through affiliation with the Science Book & Serial Exchange (SBSE). Many individual and collected reprints were received through exchange and donation, and others were acquired through interlibrary loan/photocopy for the various research sections as follows: Anadromous, 12; Botany, 35; Ecology, 16; Environmental Chemistry, 11; Fisheries, 24; Geology, 45; Library, 12; Microbiology, 27; Oyster Biology, 17; Parasitology, 49; Physical Oceanography, 18; Physiology, 56; and Systematic Zoology, 13.

Total photocopy transactions received numbered 335. There were 119 requests for interlibrary loans from other libraries.

Book purchases numbered 304 this fiscal period and the average cost per volume was $28.50. Cataloging personnel processed 502 books and 336 reprints. Donations of books, journals, reports, and reprints were received from the following institutions and individuals: University of Southern Mississippi, Department of Geology; National Marine Fisheries Service, Pascagoula Station; Ronald Lukens, Walter Brehm, John Steen, Sandra Sharp, Dr. Gordon Gunter, Dr. Ervin Otvos, Dr. Thomas Lytle, all of the Gulf Coast Research Laboratory; Dr. E. J. Harvey, Gautier, MS; Dr. B. H. Atwell, Earth Resources Laboratory, Slidell, LA; and Dr. P. Isaacson, New York Department of Public Service.

### *ICHTHYOLOGY RESEARCH MUSEUM, Mr. C. E. Dawson, Head*

Three hundred sixty-eight lots, representing approximately 1,200 specimens, were cataloged. This brings the total vertebrate holdings to 16,729 cataloged lots, about 150,315 specimens. Invertebrate holdings are 1,080 cataloged lots, about 3,460 specimens.

Important gifts of specimens, particularly Syngnathidae, were received from museums and research workers in Japan, the Philippine Islands, India, Australia and New Zealand.

Loans were made to a number of U.S. and foreign institutions, and gifts or exchange materials were provided for collections in Mexico, Australia and Belgium. Identifications were provided for fishes sent by a number of U.S. and foreign investigators.

The Gulf Coast Research Laboratory is a member institution of the Association of Systematics Collections.

### *WATER ANALYSIS LABORATORY, Dr. Thomas F. Lytle, Head*

The Analytical Chemistry Section through the Water Analysis Lab is profiling the water quality in the Pascagoula River area. Included in the parameter list are: nitrate, nitrite, ammonia, orthophosphate, total phosphorus, suspended solids, turbidity, silica, phenols and Kjeldahl nitrogen. If phenol levels warrant, more sophisticated techniques will be developed to detect individual phenol components. Presently an attempt is being made to use phenolic aldehydes as tracers of paper mill waste movements. If successful this will provide a certain degree of prediction in examining pollutant movements in rivers. All data will be used ultimately in helping State and local governments develop proper land utilization plans for the coastal zone.

*COMPUTER SECTION, Mr. David Boyes, Head*

The total number of jobs processed through the Computer Center was 3,079 with the hours run reaching 1312.53. This is a net increase of 35.8% for jobs processed and 21.0% in hours run over last year. The main sections contributing to the job total were: Du Pont Project (1,258 jobs), Oceanography (343 jobs), Finance (273 jobs), Fisheries (166 jobs), Graduate Program (155 jobs), Botany (123 jobs), and Parasitology (76 jobs); with the remaining jobs contributed by other sections.

*Pilot Study for Menhaden Catch/Effort Log* (Funded by Gulf States Marine Fisheries Commission): The main objectives of this project were: collection of catch/effort logs for the 1978 season; the design of a card format for logs; design of codes for locations, vessels, plants and species; storage of data in a compatible format with NMFS menhaden data; and preliminary analysis of the data base.

This project produced approximately 32,000 cards of data and ran 110 jobs during 1978–79.

*PUBLIC INFORMATION/PUBLICATIONS SECTION, Miss Catherine Campbell, Head*

During the last half of 1978, section personnel performed primarily publications work. One large project consisted of typing masters for the printing of a colloquium on mackerels held earlier in the year by the Gulf States Marine Fisheries Commission (GSMFC). About 120 pages were set in an 8½- by 11-inch format; this work resulted in the GSMFC publication, *Proceedings: Colloquium on the Spanish and King Mackerel Resources of the Gulf of Mexico.*

The staff also handled the printing of the Laboratory technical journal, *Gulf Research Reports.* After Dr. Harold D. Howse, editor, accepted papers for inclusion in Volume 6, Number 2, of the journal, they were copy edited by the staff for style, consistent usage and other details, then masters were typed in page format for printing the book. Work was completed during November and December; finished copies were received from the printer in late February and approximately 760 copies were mailed by the PI/P staff.

The first manuscript for Volume 6, Number 3, of *Gulf Research Reports* was received by the Section in early March 1979 and was copy edited and printing masters set. Beginning with this issue, the editor adopted deadlines for the submission of manuscripts as follows: August 1 for papers of 10 or more typewritten, double-spaced pages and September 1 for shorter papers.

Early this year, the staff began preparations for printing a new descriptive brochure for the Laboratory. Photographs were made during the summer and fall of 1978 and the booklet was written and edited. During January and February 1979, printing masters were set in 7- x 10-inch format and page layouts were made. The brochure was printed during April.

Twelve issues of the Laboratory newsletter, *Marine Briefs,* were produced and the publication completed its seventh year and entered its eighth. Staff members wrote and edited copy, took photographs, typed masters for printing and laid out pages for one 8-page, nine 6-page and two 4-page editions. Approximately 3,800 copies were distributed monthly.

During August 1978, the staff edited copy for Marine Education Leaflet No. 10, Polychaetes of Mississippi Sound, set masters and made the layout; it was printed in September. The leaflet was written by Walter Brehm of the Ecology Section. In November, the printing of the summer bulletin describing the academic program was handled by the section, and various other miscellaneous printing needs of the Laboratory were handled as they arose.

During July, August and September of 1978, the section continued to present a public information program entitled "What's in the Gulf for You?" during visits to public libraries along the Mississippi coast. Earlier, in June, visits were made to Pascagoula and Moss Point libraries and, later, to the following libraries: Biloxi, Gautier, City-County (Bay St. Louis), Gulfport-Harrison, West Biloxi and Ocean Springs. A film, "World Beneath the Sea," live exhibits and a staff member were provided by the Laboratory's Marine Education Center (MEC). Section personnel gave out free literature including Marine Education Leaflets, tide tables, shark recipes, marine careers information, and materials published by Sea Grant programs. Library personnel and patrons were made aware of the services and activities available through the MEC, the Laboratory, and Sea Grant. There was interest in continuing the program in the summer of 1979, however, due to the gasoline shortage, it was not offered.

The section provided Laboratory participation in the Mississippi State University-sponsored Harrison County Fair at Edgewater Mall Shopping City in September 1978, and in the Scout Expo' '79 at Biloxi's International Plaza and the exhibits of the annual meeting of the Mississippi Academy of Sciences in Jackson, the latter two events in March 1979.

During the spring of 1979, section personnel reworked a display panel located in the Caylor Building foyer, according to a new color scheme and design concept. This 4- x 8-foot exhibit depicts aspects of both the academic and research purposes of the Laboratory.

The section continued to disseminate information of Laboratory activities to the general public.

Thirty-five news releases were mailed to about 50 selected daily and weekly newspapers, television and radio stations, wire services and special correspondents. In addition, approximately 100 pictures were made of small groups of field trip and summer college students and these were sent, with cutlines, to hometown and campus publications throughout the country.

Assistance was provided to a number of outside writers, photographers and television crews who sought to cover activities of the Laboratory. Conducted tours were given by the staff to a dozen high school, college, and professional groups.

The section also obtained Laboratory staff members to serve as speakers for civic clubs and judges for science fairs.

## ACADEMIC PROGRAM

*NEW AFFILIATE*

Eastern Kentucky University in Richmond, Kentucky, affiliated with the Laboratory during the year. The total of out-of-state affiliates is now 39.

*SUMMER SESSION, Dr. David W. Cook, Registrar*

The 1978 summer academic session involved 91 students registering individually for a total of 120 student courses. Thirty-nine students registered through Mississippi schools, 56 through out-of-state affiliates and four through non-affiliated out-of-state institutions. Courses taught during the 1978 summer session were:

- Salt Marsh Ecology, Dr. Lionel N. Eleuterius, staff
- Marine Microbiology, Drs. David W. Cook and William W. Walker, staff
- Introduction to Marine Zoology, Dr. Buena S. Ballard, Southwestern Oklahoma State University
- Marine Vertebrate Zoology and Ichthyology, Dr. J. William Cliburn, University of Southern Mississippi
- Marine Invertebrate Zoology, Dr. Edwin W. Cake, Jr., staff
- Marine Fisheries Management, Mr. J. Y. Christmas, Jr., staff, and visiting specialists
- Marine Aquaculture, Dr. Edwin W. Cake, Jr., staff
- Marine Ecology, Drs. James T. McBee and Robert A. Woodmansee, staff
- Marine Botany, Dr. R. B. Channell, Vanderbilt University
- Parasites of Marine Animals, Dr. Robin Overstreet, staff
- Special Problems in Marine Science, staff

During the 1978–79 academic year, 35 students earned credit in the course Basic Techniques in Marine Science for Teachers, offered at night at the Marine Education Center located in Biloxi. This course was taught by Mr. Gerald C. Corcoran, staff.

*GRADUATE RESEARCH PROGRAM*

Courses offered in the Graduate Research Program during this period included: Seminar, Special Problems in Marine Science, Special Topics in Marine Science, and Graduate Research in Marine Science. A total of 72 semester hours credit were earned by these students.

Four new students were accepted into the Laboratory's Graduate Research Program during the year. Three students completed their degrees and three students completed their research projects and returned to their parent campuses for further coursework. Fourteen students in the program were candidates for the master's degree and nine candidates for the doctorate.

Each candidate's name, thesis title, degree sought and home university are listed below according to the senior staff member directing their work:

*Dr. Edwin W. Cake, Jr.:*

David H. Barnes, "Polychaetes associated with an artificial reef in the north central Gulf of Mexico," M.S., University of Southern Mississippi.

David A. Blei, "A successional study of the hydrozoans inhabiting an artificial reef in the north central Gulf of Mexico," M.S., University of Southern Mississippi.

Alfred P. Chestnut, "Substrate competition between *Crassostrea virginica* (Gmelin) and associated sessile marine invertebrates," Ph.D., University of Southern Mississippi.

William W. Falls, "Food habits and feeding selectivity of larval striped bass, *Morone saxatilis* (Walbaum), under intensive culture," Ph.D., University of Southern Mississippi.

Kenneth Hase, "Enhancement of oyster production in a tidal lagoon in a U.S. Park Service wilderness area," M.S., University of Southern Mississippi.

Katherine A. McGraw, "A comparison of the growth and survival rates of hatchery-reared and natural oyster spat at selected locations in the Mississippi Sound and adjacent waters with comments on the biology of oysters in Mississippi," Ph.D., University of Washington.

John E. Supan, "A comparison of 'off-bottom' relaying of oysters in the Mississippi Sound," M.S., University of Southern Mississippi.

*Mr. J. Y. Christmas, Jr.:*

James R. Warren, "Changes in the population of the juvenile groundfish, *Micropogonius undulatus, Leiostomus xanthurus* and *Cynoscion arenarius,* from Mississippi Sound before and after the opening of the 1979 shrimp season," M.S., University of Southern Mississippi.

*Dr. Lionel N. Eleuterius:*

James C. Garrison, "Some relationships of salt marsh vegetation to abundance of the marsh periwinkle *Littorina irrorata* Say," M.S., University of Mississippi.

Stephen H. Sky-Peck, "A study of growth and nitrogen content of *Spartina alterniflora* and *Juncus roemerianus* in response to source and concentration of nitrogen," M.S., University of Mississippi.

*Dr. Gordon Gunter:*

Zubir bin Din, "The food and feeding habits of the common bay anchovy, *Anchoa mitchilli diaphara* Hildebrand," M.S. degree awarded 1979, University of Mississippi.

*Dr. Thomas D. McIlwain:*

Frederick E. Schultz, "Description and comparison of the eggs, larvae, and young of the yellow bass, *Morone mississippiensis,* with striped bass, *Morone saxatilis,* white perch, *Morone americanus,* and white bass, *Morone chrysops,*" M.S., University of Mississippi.

*Dr. Robin Overstreet:*

Daniel R. Brooks, "Evolutionary history of digenetic trematodes infecting crocodilians, including revision of Acanthostominae Poche, 1926 (Digenea: Cryptogonimidae),"

Ph.D. degree awarded 1979, University of Mississippi.

Thomas L. Deardorff, "Nematodes of the genus *Thynascaris* Dollfus 1933, (Anisakidea) in the northern Gulf of Mexico," Ph.D., University of Southern Mississippi.

Alan C. Fusco, "The life cycle and development of *Sirocamallanus cricotus*, with notes on the taxonomic status of the genus," M.S. degree awarded 1978, University of Southern Mississippi.

Tom E. Mattis, "Larval development of two trypanorhynch tapeworms from Mississippi Sound," Ph.D., University of Southern Mississippi.

Mobashir Ahmad Solangi, "Pathological changes in some estuarine fish exposed to crude oil and its water-soluble fractions," Ph.D., University of Southern Mississippi.

*Dr. A. Venkataramiah:*

Ann L. Gannam, "Effect of replacing dietary animal protein with plant protein supplemented by methionine on the growth and survival of Penaeid shrimp," M.S., University of Southern Mississippi.

Shiao Yu Wang, "Studies on the effect of declining oxygen tension on the respiratory rate of brown shrimp, *Penaeus aztecus* Ives in relation to temperature and size," M.S., University of Southern Mississippi.

*Dr. Robert Woodmansee:*

Zoghlul Kabir, "Relationship between the diurnal vertical migration and egg development in planktonic copepods in Mississippi Sound and adjacent northern Gulf of Mexico waters," Ph.D., University of Mississippi.

John P. Steen, "Factors influencing the spatial and temporal distribution of selected crustacean plankton species in Davis Bayou," Ph.D., University of Mississippi.

Michael C. Torjusen, "The distribution, abundance and feeding habits of larval and juvenile bothid flatfishes of Mississippi Sound and adjacent waters," M.S., University of Mississippi.

#### *SCIENTIFIC FIELD TRIP PROGRAM*

As an adjunct to the teaching program, each year the Laboratory provides living accommodations, classroom laboratories, and essential services to visiting scientific field trip groups made up of college and university students and their professors. Such groups may stay for periods of up to several weeks, live in the dormitory, use Laboratory boats to make collections of marine life from the sea and from the beaches of offshore islands, and study their specimens in the classroom laboratories. During the year the Laboratory was visited by 33 field trip groups. The total number of people involved were 470 professors and students who stayed an average length of 4.18 days. Some came as far as 2,000 miles to study the marine life of the Gulf of Mexico.

### SPECIAL AND COMMUNITY SERVICES

#### *FISHERY ASSISTANCE*

*The Biloxi Schooner* (Funded by GCRL): A newsletter, designed especially for the processing segment of the seafood industry, was published monthly. It entered its second volume. The current mailing list is composed of 75 seafood companies and industry-related persons in Mississippi and five other states. Its content is technical in nature relating directly to the business of seafood production. Source material comes from Laboratory research, trade journals, scientific papers, Federal agency publications, and information gathered at seminars, conferences, and trade conventions.

*Seafood Merchandising Circular—Oysters* (Funded by GCRL): In the previous year an educational fact sheet had been written at the request of a seafood packers association, to help food distributors and retailers better understand the nature of oysters. It was the intent of this fact sheet that better handling and selling would result by making more people in the food distribution chain better acquainted with this highly perishable product. A supply of waterproof paper was located and 3,000 copies were printed and given to oyster packers to put in their boxes of iced oyster jars before shipment to stores throughout the country.

*Wastewater Sampling Program* (Funded by GCRL): To prepare the seafood industry for strict requirements of water pollution regulations administered by the EPA. this program was set up to test seafood plant wastewater effluent. The objective is to measure the "conventional pollutants" as defined by the EPA. There are limits on the amounts of these pollutants that can be contained in plant effluent if it is discharged into local waters rather than into a sewerage system. If samples tested show that a plant's wastewater contains more than the allowable amounts of pollutants, then a plan is drawn up to help the particular plant lower these levels.

The state pollution control agency operates a wastewater discharge permit system subject to EPA approval; weekly sampling and a monthly report are required. Test results from this sampling program are reported to plant owners, who in turn use these data in their reports to the state. Data are gathered on each product processed. From December through June, 38 complete sample sets were made, which required spending 155.5 hours during 62 visits to the plants.

These data will be of added benefit to the seafood industry in relation to the proposed regional sewerage system being planned by the state and EPA. Eventually that system will require all seafood plants to discharge their effluents into a treatment plant. A sewer-use ordinance will be drawn up setting allowable levels of pollutants entering the treatment plant. Data being accumulated from this sampling program will be of future value in helping to obtain realistic ordinance limitations.

Due to the complexity and potential impact of the EPA's wastewater guidelines, a reference library was started to keep this office informed and serve as a source of information for the seafood industry. The collection now contains a set of the laws, their amendments, and up-to-date rule changes;

a 15-volume collection of documents developed to facilitate compliance of the food industry with the regulations; and research papers and other reference materials that have been developed on the seafood industry.

*ADDITIONAL ASSISTANCE*

Extensive freezing and packaging experiments for a number of seafood products were begun at the request of a processor. This is a continuing project carried on at the seafood plant. The experiments involve product preparation, freezing time/temperature studies, packaging material evaluation, and quality determination.

Assistance was requested by an industry member who wanted to locate a volume source for several species of fish that were in high demand but could not be supplied locally. A marketing study was done of catch and distribution data from the southeastern states. The study defined a middle-Atlantic coast state as a good source of supply which was also within a reasonably economical transportation range from the Gulf coast. The names of fish dealers in that area were obtained and contact was made.

Three industry members requested assistance concerning a seafood product shipping regulation. A study of published research was done to examine the basis for the regulation and gather support data for any proposed changes. These data were compiled in a statement on the issues involved with the regulation. This matter is currently under consideration by the seafood industry at the national level. This work will carry over into next year.

*ENVIRONMENTAL AFFAIRS*

The Environmental Affairs Committee is composed of all senior scientific staff members and is coordinated by the Ecology Section. The committee provided an interdisciplinary approach to environmental problems in the wetlands and estuaries of Mississippi, primarily as a service to the Mississippi Marine Resources Council, which partially funded this work. However, the committee also cooperates with other State and Federal agencies on special projects that are not under the direct jurisdiction of the Council. The majority of this work deals with the review of permit requests for work proposed in the wetlands and estuaries. Committee members made comments and recommendations on permit requests. In most cases a site visit was made by representatives of the Committee. Based upon these inputs, a letter to the Council was drafted stating any objections the Committee might have, reasons for those objections, and recommendations that might reduce or eliminate the objections.

The Committee reviewed 54 permit applications during the year. In addition, a statement on the proposed 201 Regional Water Pollution Abatement Plan was drafted and presented at a public hearing convened by the Mississippi Air and Water Pollution Control Commission. Five members of the Committee were also members of the Deer Island Study Committee which was formed to assess the impact of a proposed skylift transportation system and the potential impact of 600 visitors per hour on the flora and fauna of Deer Island and the surrounding waters.

*PUBLIC SEMINARS*

The Gulf Coast Research Laboratory hosts a series of staff seminars throughout the year. These seminars are open to the public and speakers include invited scientists as well as officials from various levels of local, state and federal government. The central purpose of the seminars is to promote better dissemination, understanding, and use of scientific information at all levels of society. Seminars presented during fiscal year 1979 were as follows:

*"Principles of Health Physics in the Radiochemistry Laboratory"* by Mr. Ronald J. Forsythe, Assistant Director, and Mr. Kenneth Waller, Health Physicist, Regulatory Agent, Radiological Health Division, Mississippi State Board of Health, July 11, 1978.

*"Planetarium Science"* by Mr. Jim McMurtray, Director, STARS Planetarium, July 25, 1978.

*"Evolution of Several Marine Invertebrate Groups as Interpreted from the Fossil Record"* by Mr. Jim Garrison, Botany Section, Gulf Coast Research Laboratory, July 28, 1978.

*"Transport and Fate of Organic Compounds in Rivers and other Gulf Coast Hydroscience Center Research"* by Dr. Dave Shultz, U.S. Geological Survey, Research Hydrologist, National Space Technology Laboratories, August 8, 1978.

*"Testing Hypotheses of Evolutionary Histories of Parasitic Helminths"* by Mr. Daniel R. Brooks, Parasitology Section, Gulf Coast Research Laboratory, August 15, 1978.

*"Mississippi Cooperative Extension Service. . . .Research and Services"* by Mr. Leonard Slade, Jackson County Extension Agent, August 22, 1978.

*"Mechanics of Enhanced Recovery"* by Mr. Dave Meltzer, Senior Reservoir Engineer, Secondary Recovery Offshore Platforms, Chevron U.S.A., Inc., September 12, 1978.

*"Trends in Medical Research"* by Dr. James B. Martin, M.D., Ocean Springs, September 26, 1978.

*"Salient Vegetative Features of Tidal Marshes and Evolutionary Implications from Plant Autecology"* by Dr. Lionel Eleuterius, Head, Botany Section, Gulf Coast Research Laboratory, October 10, 1978.

*"Future Plans of Mississippi Power in Developing Energy Reserves"* by Dr. Harry H. Bell, Jr., Vice President Engineering and Operations, Mississippi Power Company, October 24, 1978.

*"Assembly Line, Modular Production of Ships at Ingalls Shipbuilding"* by Mr. A. C. Weeks, Litton Industries, Ingalls Shipbuilding Division, November 7, 1978.

*"Hurricane Meteorology and Reconnaissance"* by Capt. Jim Perkins, Meteorologist, Keesler Air Force Base, November 21, 1978.

*"Ecology of the Birds of Horn and Ship Islands, Mississippi"* by Mr. Wayne C. Weber, Department of Biological Sciences, Mississippi State University, November 28, 1978.

*"Food and Feeding Habits of the Common Bay Anchovy, Anchoa mitchilli"* by Mr. Zubir bin Din, Physiology Section, Gulf Coast Research Laboratory, November 30, 1978.

*"Tick-Borne Rickettsial Diseases in Mississippi"* by Dr. Lane Foil, Department of Entomology, Mississippi State University, December 5, 1978.

*"The Gill Netting-Sport Fishing Controversy in the Mississippi Sound"* by Dr. Wendell Lorio, Director, Mississippi State University Research Center, National Space Technology Laboratories, January 16, 1979.

*"Gulf Teleost Cell Structure"* by Dr. Joe Wharton, Department of Microbiology, University of Mississippi Medical Center, January 23, 1979.

*"Marine Advisory Program Activities and Coastal Development"* by Dr. David Veal, Mississippi Sea Grant Advisory Service, February 20, 1979.

*"Methods of Handling and Shedding Blue Crabs"* by Ms. Harriet Perry and Mr. Larry Nicholson, Fisheries Section, Gulf Coast Research Laboratory, March 6, 1979.

*"Effects of Changes in Salinity on Biochemistry and Surface Ultrastructure of the Gill of the Mullet, Mugil cephalus"* by Dr. Fred Hossler, Department of Anatomy, Louisiana State University Medical Center, March 20, 1979.

*"Fish Eggs and Larvae: A Resource Assessment Tool"* by Dr. Sally L. Richardson, Fisheries Section, Gulf Coast Research Laboratory, April 10, 1979.

*"Present Status of Larval Taxonomy of Myctophid Fishes"* by Dr. Muneo Okiyama, Associate Professor, Division of Marine Ecology, Ocean Research Institute, University of Tokyo, April 11, 1979.

*"Utilization of Seafood Products"* by Mrs. Bertha Fontaine, Seafood Consumer Specialist, National Marine Fisheries Service, April 24, 1979.

*"Home Health Service in Jackson County"* by Nica Cason, R.N. and Joyce Rivera, R.N., Public Health Nurses, Jackson County Health Department, May 8, 1979.

*"Geology of the Gulf Coast"* by Dr. Ervin Otvos, Head, Geology Section, Gulf Coast Research Laboratory, May 22, 1979.

*"Toxicology Capabilities at the Gulf Coast Research Laboratory"* by Dr. William Walker, Microbiology Section, Gulf Coast Research Laboratory, June 5, 1979.

*"A Study of Growth and Nitrogen Content of Spartina alterniflora* and *Juncus roemerianus in Response to Source and Concentration of Nitrogen"* by Mr. Stephen Sky-Peck, Botany Section, Gulf Coast Research Laboratory, June 21, 1979.

*"Basic Studies in Reproduction Using Nematodes as Experimental Models"* by Dr. Eugene Foor, Wayne State University, June 26, 1979.

## STAFF PUBLICATIONS

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______ and Gerald D. Schmidt. 1978. *Acanthotaenia overstreeti* sp. n. (Cestoda: Proteocephalidae) from a Puerto Rican lizard, the first acanthotaeniine in the new world. *Proceedings of the Helminthological Society of Washington* 45(2):193–195.

Buckner, Richard L., Robin M. Overstreet, and Richard W. Heard. 1978. Intermediate hosts for *Tegorhynchus furcatus* and *Dollfusentis chandleri* (Acanthocephala). *Proceedings of the Helminthological Society of Washington* 45(2):195–201.

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Dawson, C. E. 1978. Review of the Indo-Pacific pipefish genus *Bhanotia*, with description of *B. nuda* n. sp. *Proceedings of the Biological Society of Washington* 91(2): 392–407.

______ . 1978. Description of a new Western Australian pipefish (*Choeroichthys latispinosus*), with notes on *Syngnathus tuckeri* Scott and *Nannocampichthys* Hora and Mukerji. *Records of the Western Australian Museum* 6(4):413–421.

_______ and G. R. Allen. 1978. Synopsis of the "finless" pipefish genera (*Penetropteryx*, *Apterygocampus* and *Enchelyocampus*, gen. nov.). *Records of the Western Australian Museum* 6(4):391–411.

_______ . 1979. A new wormfish (Pisces: Microdesmidae) from the eastern tropical Atlantic. *Copeia* 1979(2): 203–205.

_______ , F. Yasuda and C. Imai. 1979. Elongate dermal appendages in species of *Yozia* (Syngnathidae) with remarks on *Trachyrhamphus*. *Japanese Journal of Ichthyology* 25(4):244–250.

Deardorff, Thomas L. and Daniel R. Brooks. 1978. *Passerilepis schmidti* sp. n. (Cestoidea: Hymenolepididae) from the blue jay, *Cyanocitta cristata* L. in Nebraska. *Proceedings of the Helminthological Society of Washington* 45(2):190–192.

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Gulf Research Reports

Volume 6 | Issue 3

January 1979

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DOI: 10.18785/grr.0603.01



Recommended Citation

McBee, J. T. and W. T. Brehm. 1979. Macrobenthos of Simmons Bayou and an Adjoining Residential Canal. Gulf Research Reports 6 (3): 211-216.
Retrieved from http://aquila.usm.edu/gcr/vol6/iss3/1

*Gulf Research Reports,* Vol. 6, No. 3, 211–216, 1979.

# MACROBENTHOS OF SIMMONS BAYOU AND AN ADJOINING RESIDENTIAL CANAL

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*ABSTRACT* Species composition, abundance and seasonal variations of benthic macroinvertebrates in Simmons Bayou, Mississippi, and an adjoining dead-end canal were investigated from July 1976 through June 1977. Cluster analysis of the data summed over five stations indicated four major time periods: July, August–November, December–February, and March–June. Polychaetes and oligochaetes were most abundant in the winter and spring, amphipods in the summer, and chironomids in the spring. Temporal changes in abundance of polychaetes, oligochaetes, and chironomids appeared to reflect seasonal reproductive cycles. The peak in amphipod density corresponded with dense growths of *Ruppia maritima*. Within the dead-end canal, poor water quality and reduced infaunal densities appeared to be limited to the deeper water behind the sill.

## INTRODUCTION

In recent years the Mississippi Gulf Coast has experienced a rapid growth in human population. Accompanying this growth has been an increased demand for residential and recreational waterfront property. Because such property is in short supply, regulatory agencies have received increased numbers of requests for permits to dredge canals through marsh lands to provide open water access to one or more homesites. These proposed canals are usually dead ended.

Regulatory agencies require sound biological information to determine if the proposed alterations would be detrimental to the environment. For the coastal areas along the northeastern Gulf of Mexico this information is largely lacking. Available studies on coastal canals from the area (Paulson et al. 1974, Paulson and Pessoney 1975) concentrate on hydrology and plankton with the benthos given only cursory attention.

The purpose of this project was to study the bottom-dwelling macroinvertebrates in a dead-end residential canal and in the nearby natural waterways. Comparisons of species composition of macrobenthos from the natural waterway were made with that from the canal. Seasonal variations of the benthos from the area were also investigated.

## AREA DESCRIPTION

The study site was located in Simmons Bayou, a part of the Davis Bayou system, which empties into the Mississippi Sound near the mouth of Biloxi Bay (Figure 1). Water movement in the study area resulted primarily from tidal action with some freshwater runoff occurring during periods of heavy rainfall. Five stations were established—two in a natural bayou, two in a dead-end canal, and one in a dredged area of Simmons Bayou. Benthic samples and hydrological data were collected 17 times at these five stations at intervals of 17 to 31 days, from July 1976 through June 1977.

Stations 1 and 2 were located in an unnamed natural bayou. This bayou meanders through a *Juncus* marsh and is connected to Simmons Bayou at both ends. Water depths at these stations ranged from 30 to 120 cm depending on the state of the tide and direction of the wind.

Stations 3 and 4 were located in a dredged dead-end canal. Permanent residences and small fishing camps border the west side and the south end of the canal. A small fringe area of marsh grasses and bushes borders the east bank. Water depth at the mouth was reduced by a sill. Station 3 was located near the upper end of the canal with water depths of 120 to 185 cm. Station 4 was located near the mouth of the canal on top of the sill in water depths of 30 to 120 cm.

Station 5 was located in a portion of Simmons Bayou which was dredged through the marsh about 15 years ago. The south bank is an upland area covered with pine trees and dense underbrush while the north bank borders a large marsh area. Samples were taken in water depths of 60 to 150 cm.

Samples at stations 1, 2, 3, and 4 were taken in mid-channel. At station 5, samples were taken along the north bank. At all stations the substrate was sandy mud with considerable organic detritus.

## MATERIALS AND METHODS

Measurements of temperature and dissolved oxygen were made with a Yellow Springs Instrument Co. Model 57 oxygen meter. Salinities were measured with an American Optical Goldberg refractometer. Benthic samples were collected with a 15.3 x 15.3 cm Ekman grab mounted on a 1.5 m handle. A single bottom sample was collected at each station during each sampling period. The sediment was washed into a 0.52 mm screen with fresh water, the residue preserved with 10% formalin and stained with rose bengal. Benthic organisms were hand sorted from the screened residue under an illuminated magnifier, identified, counted, and stored in 70% ethanol. Cluster analyses, using the Bray-Curtis dissimilarity index and flexible sorting (Stephenson 1972), were used to compare stations to investigate temporal changes. The "cluster intensity coefficient" $\beta$ was set at the now conventional value of -0.25 (Boesch 1973).

Manuscript received June 6, 1979; accepted July 31, 1979.

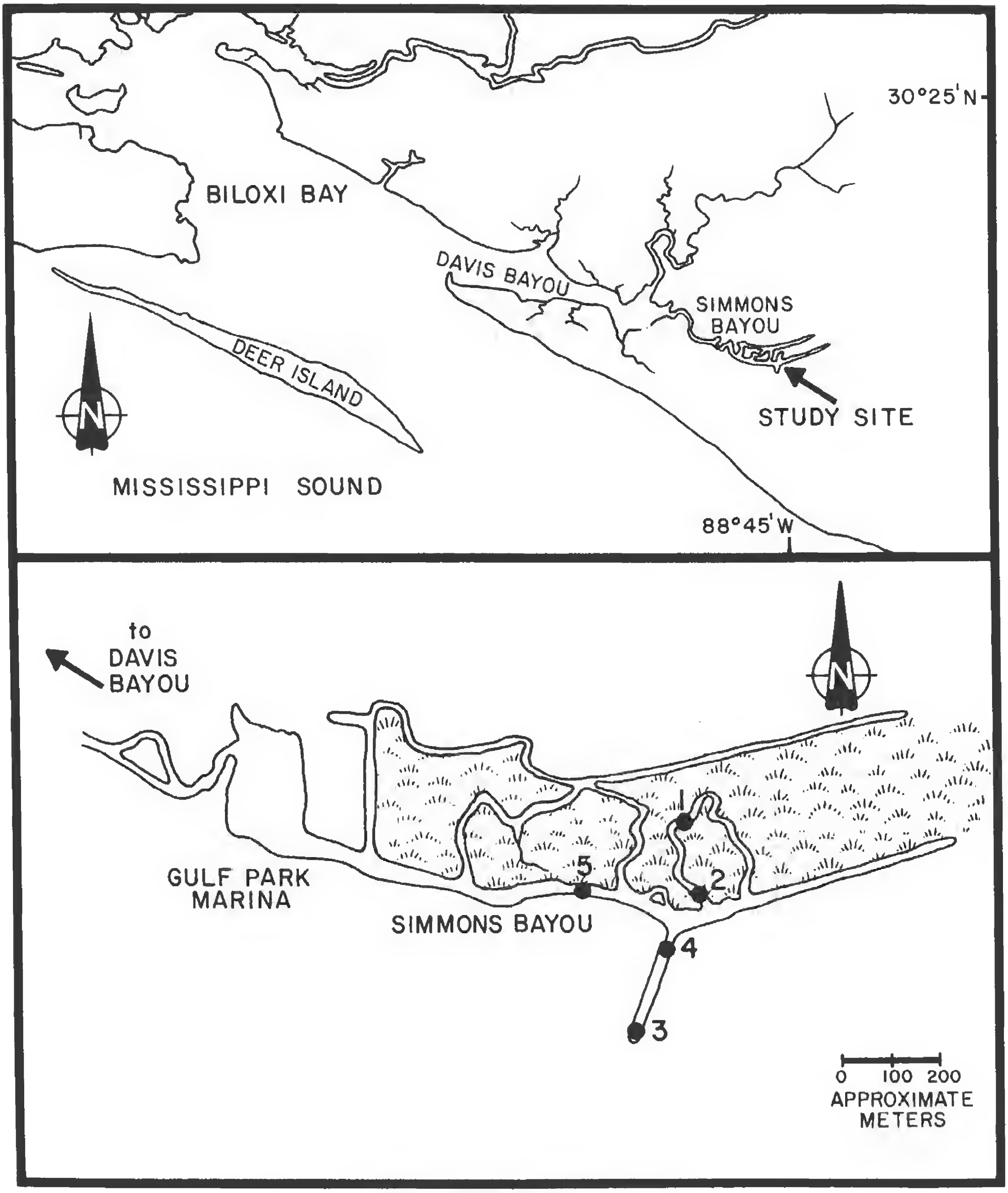


Figure 1. Area map and station locations.

## RESULTS AND DISCUSSION

During the study 16,115 organisms representing 45 taxa were collected. Of these taxa, 34 were identified to genus or species level (Table 1). This list includes a saccoglossan, *Elysia chlorotica*, and a turbellarian, *Canatellia* sp., not previously reported from Mississippi. The range of the sabellid polychaete *Manayunkia speciosa* was extended to the Gulf of Mexico (Brehm 1978).

**TABLE 1.**

**Benthic fauna found in Simmons Bayou and an adjacent dead-end canal.**

| | | |
|---|---|---|
| **Phylum Cnidaria** | | |
| | Class Hydrozoa | |
| | | unidentified hydrozoan species |
| **Phylum Platyhelminthes** | | |
| | Class Turbellaria | |
| | | *Canatellia* sp. |
| **Phylum Rhynchocoela** | | |
| | Class Anopla | |
| | | *Micrura leidyi* (Verrill) |
| **Phylum Mollusca** | | |
| | Class Gastropoda | |
| | | *Anadara* sp. |
| | | *Elysia chlorotica* (Agassiz) |
| | | Hydrobiidae |
| | | *Neritina reclivata* Say |
| | | unidentified nudibranch species |
| | Class Bivalvia | |
| | | *Macoma mitchelli* Dall |
| | | *Rangia cuneata* Gray |
| | | *Tegula* sp. |
| **Phylum Annelida** | | |
| | Class Polychaeta | |
| | | *Capitella capitata* (Fabricius) |
| | | *Eteone heteropoda* Hartman |
| | | *Hypaniola floridana* (Hartman) |
| | | *Laeonereis culveri* (Webster) |
| | | *Lumbrineris coccinea* (Renier) |
| | | *Manayunkia speciosa* Leidy |
| | | *Mediomastus californiensis* Hartman |
| | | *Parandalia americana* Emerson & Fauchald |
| | | *Polydora ligni* Webster |
| | | *Stenoninereis martini* Wesenberg-Lund |
| | | *Streblospio benedicti* Webster |
| | Class Oligochaeta | |
| | | unidentified oligochaete species |
| | Class Hirudinea | |
| | | unidentified hirudinid species |
| **Phylum Arthropoda** | | |
| | Class Insecta | |
| | | unidentified chaeoborine species |
| | | unidentified chironomid species |
| | | unidentified corixid species |
| | Class Crustacea | |
| | | *Almyracuma* sp. |
| | | *Ampelisca abdita* Mills |
| | | *Callinectes sapidus* Rathbun |

**TABLE 1. Continued**

| | | |
|---|---|---|
| | | *Corophium louisianum* Shoemaker |
| | | *Cyathura polita* (Stimpson) |
| | | *Edotea montosa* (Stimpson) |
| | | *Eurytemora* sp. |
| | | *Gammarus mucronatus* Say |
| | | *Grandidierella bonnieroides* Stephensen |
| | | *Hargeria rapax* (Harger) |
| | | *Macrocyclops* sp. |
| | | *Melita nitida* Smith |
| | | *Parametopella cypris* (Holmes) |
| | | *Penaeus aztecus* Ives |
| | | unidentified harpacticoid species |
| | | unidentified mysidacean species |
| | | unidentified ostracod species |

### *Hydrological Data*

Bottom water temperatures, salinities, and dissolved oxygen concentrations at stations 1, 2, 4, and 5 were similar throughout the study (Figure 2). Although temperatures and salinities at station 3 approximated the other stations for eight months of the study, these parameters were appreciably higher at station 3 than at the other stations from November through March. During this period the salinities of the bottom water were as much as 13‰ higher than the surface readings and bottom water temperatures were up to 6°C warmer than the surface layers. This indicates that the water column at station 3 was stratified from November through March.

The dissolved oxygen concentrations of the bottom waters were always lower at station 3 than at the other stations (Figure 2). These differences were greatest from November through March when the water column was stratified.

### *Seasonal Effects*

Cluster analysis of the species data summed over the five stations for each collection period indicated strong seasonality (Figure 3). There was a summer (July), a late summer-fall (August–November), a winter (December–February), and a spring period (March–June). Differences between the seasons were due to changes in abundance of polychaetes, oligochaetes, amphipods, and chironomids (Table 2). Polychaetes and oligochaetes were most numerous in the winter and spring, amphipods were most abundant in the summer, and chironomids exhibited their greatest density in the spring.

Temporal divisions noted in this study appeared to reflect changes in species composition associated with seasonal spawning cycles of benthic macroinvertebrates. The recruitment of large numbers of juveniles during the winter and spring indicated spawning occurred during the cooler months. Tenore (1972) attributed vast seasonal changes in species composition and density in the Pamlico River

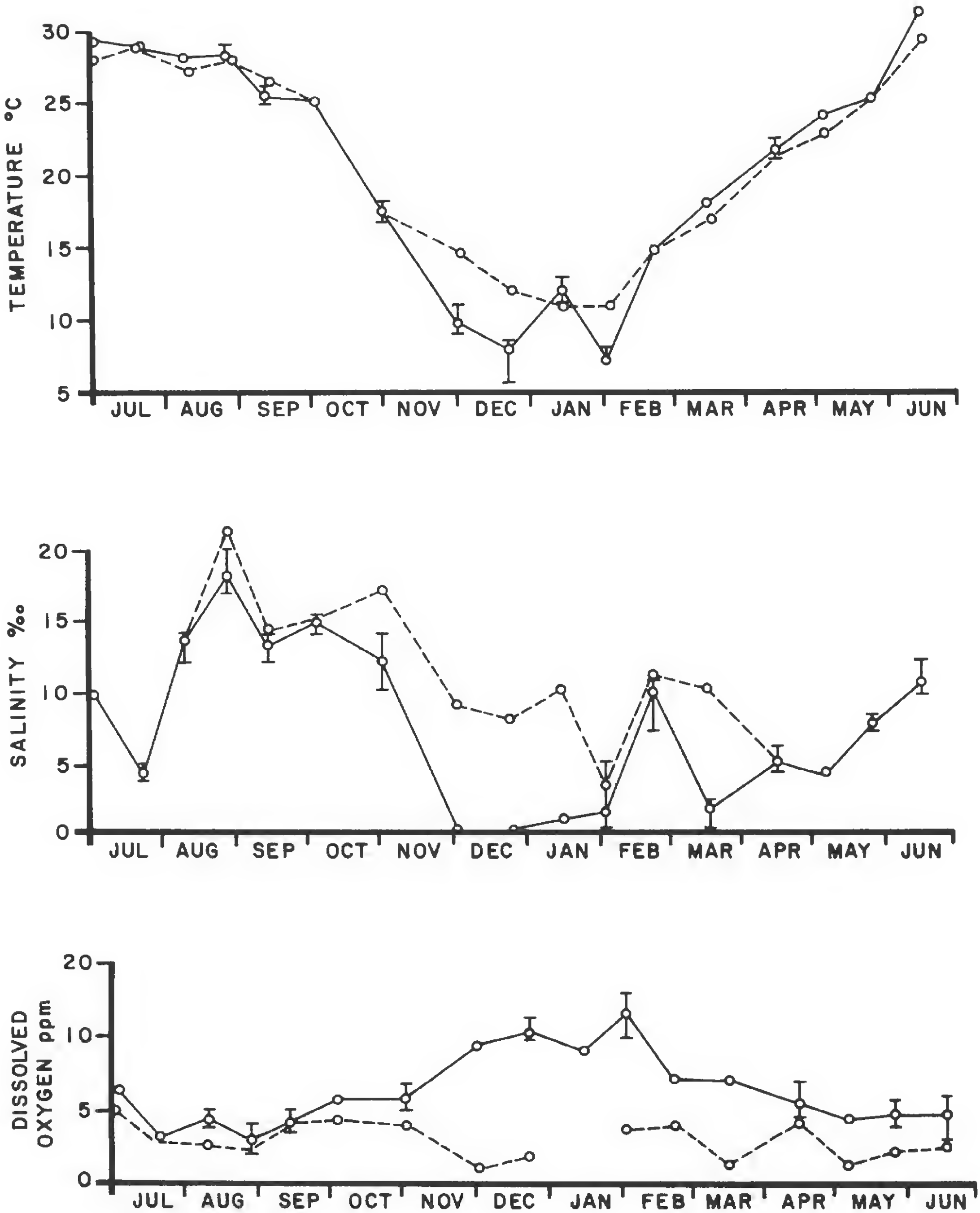


Figure 2. Bottom water temperature, salinity and dissolved oxygen in Simmons Bayou. Solid line represents mean and range of values for stations 1, 2, 4, and 5. Broken line represents station 3.

estuary to settling of juvenile forms during the fall and spring. Boesch (1973) reported that many species in Chesapeake Bay successfully spawn during both spring and fall, and others may be more successful only in one of the seasons. The data presented here indicate a pattern similar to the findings of Tenore (1972) and Boesch (1973).

The amphipods had their greatest recruitment during the cooler months but the abundance of these organisms in the summer appeared to be influenced by the amount of aquatic vegetation. During July dense growths of the submerged aquatic angiosperm *Ruppia maritima* were present throughout Simmons Bayou, especially at stations 1 and 2. The *Ruppia* died back in the fall and was not observed again during the study. Apparently this aquatic plant provided a favorable habitat for the amphipods, thus they were able to maintain high population densities (10419/m$^2$) through part of the summer. Amphipod abundance dropped drastically during the fall, along with the disappearance of the *Ruppia*.

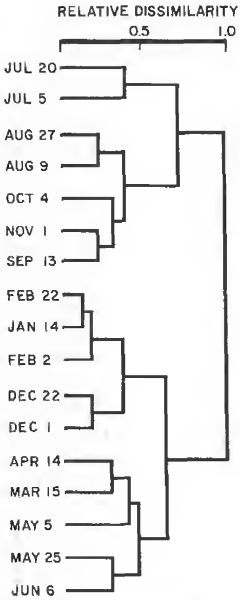


**Figure 3. Clustering of combined stations by collection period using Bray-Curtis dissimilarity index and flexible sorting.**

TABLE 2.

**Mean density in individuals/m$^2$ of selected faunal groups during each season at Simmons Bayou.**

| | Summer 2 July– 20 July | Late summer– Fall 4 August– 1 November | Winter 1 December– 22 February | Spring 15 March– 16 June |
|---|---|---|---|---|
| Polychaetes | 1,550 | 4,219 | 34,961 | 14,510 |
| Oligochaetes | 3,660 | 4,951 | 22,260 | 14,897 |
| Amphipods | 10,419 | 603 | 6,114 | 8,181 |
| Chironomids | 2,024 | 86 | 1,765 | 7,879 |

### *Station Differences*

Cluster analysis of species data summed for all collections (Figure 4) indicated that stations 1, 2, 4, and 5 were relatively similar to each other and very dissimilar to station 3. This large degree of dissimilarity was due to the greatly reduced number of species and individuals at station 3. Total densities of the benthic infauna were relatively high for stations 1, 2, 4, and 5 and greatly reduced at station 3 (Table 3). In fact, during the entire sampling period only 140 individuals, representing 17 species, were collected at station 3. This compares with approximately 45 species and 4,000 individuals at each of the other stations.

Biological studies of multi-branched housing-development canals from other areas indicated that species composition and abundance of benthic organisms were detrimentally affected due to highly organic sediments and reduced water quality (Taylor and Saloman 1968, Barada and Partington 1972, Gilmore and Trent 1974, Lindall and Trent 1975). Although the canal system in this study was relatively short and unbranched, its overall effect appeared to be very similar to other canal systems. Densities of macroinvertebrates at station 3 were significantly lower ($\alpha$ = .01) than the other stations (Table 3). Although densities at all stations increased during the cooler months due to recruitment, this

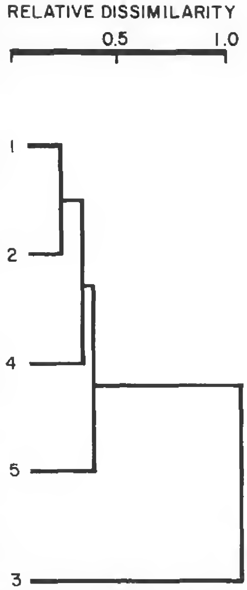


**Figure 4. Clustering of combined collection periods by station using Bray-Curtis dissimilarity index and flexible sorting.**

TABLE 3.

**Comparison of density, in organisms/m$^2$, of benthic macroinvertebrates of Simmons Bayou stations.**

| Date | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 |
|---|---|---|---|---|---|
| 2 Jul 76 | 129 | 22,174 | 0 | 5,425 | 646 |
| 20 Jul | 258 | 3,229 | 301 | 2,928 | 1,076 |
| 9 Aug | 388 | 7,621 | 258 | 1,249 | 3,961 |
| 27 Aug | 1,076 | 5,425 | 43 | 2,540 | 2,239 |
| 13 Sep | 344 | 3,832 | 0 | 2,339 | 4,349 |
| 4 Oct | 474 | 2,411 | 0 | 1,464 | 1,722 |
| 1 Nov | 2,583 | 3,229 | 646 | 775 | 4,047 |
| 1 Dec | 13,476 | 17,222 | 2,368 | 8,783 | 7,233 |
| 22 Dec | 19,806 | 19,332 | 732 | 9,343 | 7,406 |
| 14 Jan 77 | 36,296 | 34,617 | 86 | 31,689 | 9,171 |
| 2 Feb | 40,214 | 20,408 | 344 | 32,248 | 12,056 |
| 22 Feb | 21,528 | 37,200 | 646 | 16,921 | 11,840 |
| 15 Mar | 22,475 | 9,558 | 0 | 10,032 | 12,529 |
| 14 Apr | 7,276 | 4,133 | 43 | 10,549 | 16,103 |
| 5 May | 1,464 | 5,511 | 0 | 14,338 | 5,769 |
| 25 May | 5,554 | 5,296 | 172 | 5,985 | 15,845 |
| 16 Jun | 2,885 | 2,411 | 388 | 3,100 | 32,206 |

period coincided with stratification of the water column in the dead-end canal and total densities at station 3 never reached those of the other stations. Apparently the larvae were either unable to settle at station 3 due to the reduced circulation and stratification or they did not survive because of the low dissolved oxygen content of the water.

The area of poor water quality and reduced infaunal densities in the dead-end canal appeared to be limited to bottom areas behind the sill. Hydrographic measurements (Figure 2), infaunal densities (Table 3), and the results of the station clustering (Figure 4) indicated that the unfavorable environmental conditions observed at station 3 did not occur at station 4. This was apparently due to the sill across the mouth of the dead-end canal. The sill acted as a dam, restricting water circulation to the surface layers, and contributed to the stratification and stagnation of bottom waters behind it. Thus, station 4, located on top of the sill in the circulating layer, appeared to be unaffected while station 3, located behind the sill in deeper water, had the reduced faunal densities and hydrological characteristics described by Barada and Partington (1972) and Gilmore and Trent (1974) as being typical of dead-end canals.

## ACKNOWLEDGMENTS

The authors wish to thank Dr. Louise Bush for identification of *Canatellia* sp.; Drs. Edwin Cake, Adrian Lawler, Thomas McIlwain and Robert Woodmansee, and Mr. John Steen for their advice and counsel in reviewing the manuscript; and Mr. Jerry McLelland for his help in collecting samples.

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


## Patterns of Suspended Particle Transport in a Mississippi Tidal Marsh System


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DOI: 10.18785/grr.0603.02

*Gulf Research Reports*, Vol. 6, No. 3, 217–224, 1979.

# PATTERNS OF SUSPENDED PARTICLE TRANSPORT IN A MISSISSIPPI TIDAL MARSH SYSTEM[1]

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*ABSTRACT* The flux of suspended particulate organic detritus (POD) and suspended inorganic detritus (PID) was studied during ten diurnal tidal periods (24-hour) and three semi-diurnal tidal periods (12-hour) between May 1975 and April 1976. The concentration of POD ranged from 1.50 to 19.79 mg/l, while the PID ranged from 3.20 to 99.61 mg/l. There was a net export of POD during four of 13 tidal periods and a net export of PID during five tidal periods. There was a total net movement of 39.32 and 292.51 kg of POD and PID, respectively, into the marsh. On an annual basis, this is equivalent to the addition of 168 $g/m^2/yr$ of detrital material to the marsh.

The predictability of POD and PID concentration in the water was good ($r^2$ of 57.9 and 58.1%) during ebb tide based on nine biological and physical variables. The ratio of POD to total suspended material was 15.9% and constant during the year at all concentrations.

Although the marsh may not be an important source of carbon for the estuary, data indicate that the marsh may regulate the concentration of suspended detritus in the nearby bay by releasing detritus when the detritus concentration in the water is low and by accumulating detritus when this concentration is high.

## INTRODUCTION

The high productivity of tidal marshes and the presence of high concentrations of particulate organic matter in adjacent coastal waters has led to the conclusion that tidal marshes export much of the carbon fixed by vascular plants on the marsh. An early study (de la Cruz 1965) of the transport of particulate organic detritus substantiated this initial conclusion. Recent investigations, however, suggest that the export of organic carbon from tidal marshes may not be a general phenomenon (Nadeau 1972; Heinle and Flemer 1976; Shisler and Jobbins 1977; Woodwell et al. 1977), while other transport studies support the traditional view of a net detrital export (Heald 1969; Moore 1974; Settlemyre and Gardner 1977). Some variation in detritus transport should be expected among tidal marsh systems which differ in their vegetation, tidal regime (diurnal or semi-diurnal), tidal range, freshwater input from rivers and geographic orientation with respect to the nearby open water and prevailing winds. Factors which might enhance the movement of particulate material on and off the marsh have not been evaluated with respect to the concentration of particulate material and its subsequent transport in the marsh system.

This study examines the concentration of suspended particulate material (organic and inorganic) in a tidal creek draining an irregularly flooded *Juncus* marsh in Mississippi. The effects of 13 biological and physical variables on the concentration of detrital material during the ebb and flood stages of the tidal cycle were determined. In addition, the role of tidal marshes and particulate organic detritus in the productivity of estuaries was reexamined based on the current investigations and on the basis of recent works by other investigators.

## STUDY AREA

The study area is located on the southeastern end of a deltaic island deposited by the Jourdan River. The marsh island is on the western side of St. Louis Bay in Hancock County, Mississippi (Figure 1). The study area included 5.84 ha of watershed drained by a small creek which in turn empties into Catfish Bayou. The creek channel is 95 m long, and 4 to 6 m wide along most of its length. The creek channel has steep banks, but is not deeper than 1 m during mean low tide. The upper reaches of the creek are shallow (less than 20 cm) during low tide and are characterized by very soft bottom sediments, while areas of the creek near the mouth have firm mud substrates. The creek never drains completely, even during the lowest tides. A small bar at the mouth of the creek retains water in the creek when the water level is lower in the adjoining bayou.

## MATERIALS AND METHODS

### *Hydrology*

A survey of the study area was made on February 21 and 22, 1975, and the elevation of the marsh was determined to the nearest 2.6 cm using standard survey equipment. The watershed of the study creek was determined by finding the highest point between the study creek and other nearby bodies of water. Where no elevated areas existed, the watershed was estimated by including half of the area between the study creek and the body of water in question.

The volume of water moving in and out of the creek was

[1] Research partially supported by grants from the National Science Foundation, Oceanography Section (NSF No. GA–35715) and from the Mississippi Marine Resources Council (MMRC No. GR–76–003).

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Manuscript received February 26, 1979; accepted May 22, 1979.

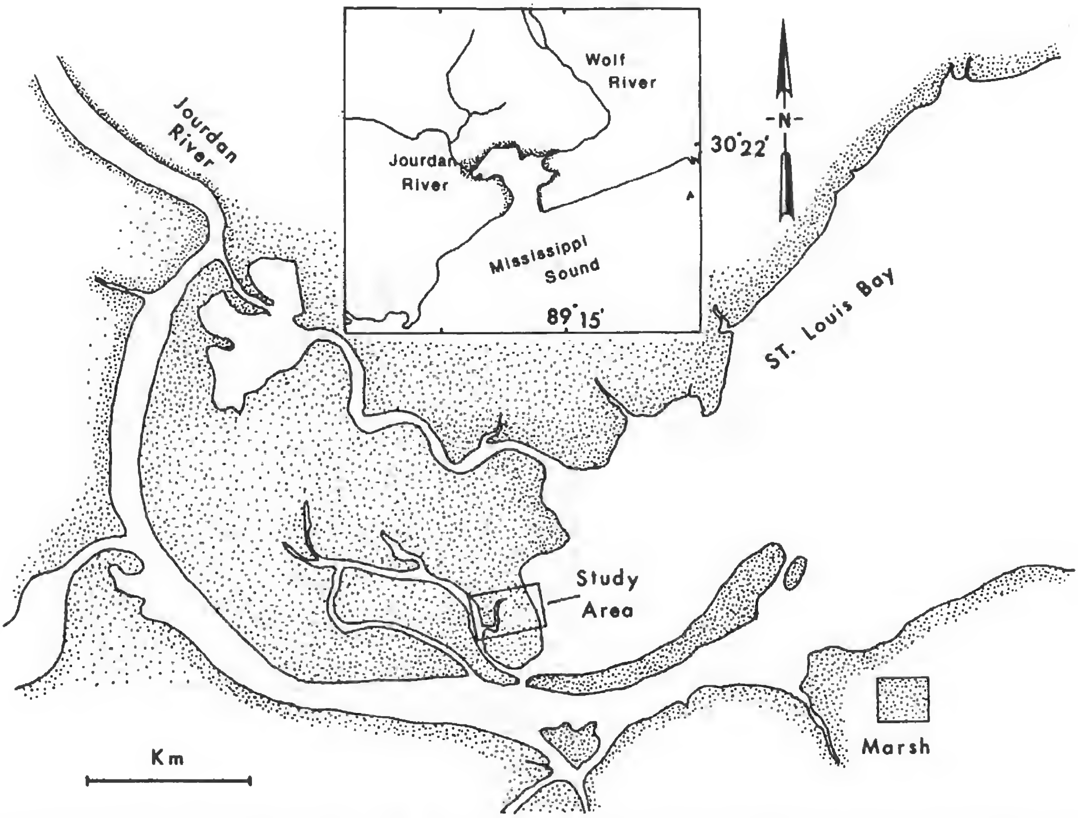


**Figure 1. The western side of St. Louis Bay showing the marsh island on which the study area is located. Insert shows the location of the Wolf and Jourdan rivers relative to St. Louis Bay.**

determined by two methods. When the tidal height was above the creek banks, adequate water currents were present and a current meter (Weathermeasure Corporation Model F-582) was used to directly measure water flow. The current was measured approximately 20 cm below the surface. The current meter was accurate to ± 0.02–0.05 m/s within the current range observed. The volume of water was calculated by multiplying the current velocity by the cross sectional area of the creek at the point of measurement. The cross sectional area of the creek was determined by measuring the depth of the creek every 0.5 m across the mouth of the creek and graphically producing an area of the mouth's cross section for any level of water based on a permanent tidal gauge in the creek. For every unit (cm) increase or decrease of the tidal height the cross sectional area of the creek changed correspondingly. When the water level was below the creek bank, no measurable current was present. Water movement was determined by changes in the volume of water present in the creek. This was determined by measuring the cross sectional area of the creek at representative points and determining the volume of the creek at any given tidal height, using a permanent tidal gauge located within the creek as a reference point. Thus, a 1-cm change of water level was accompanied by a known volume change at any point in the tidal cycle.

The volume of water entering or leaving the creek is important in the calculation of net import or export of suspended materials during a tidal cycle. The weak diurnal tides along the Mississippi Gulf coast seldom return to the same level at the end of a tidal cycle. A suspended particulate matter budget which does not account for this difference would be inaccurate, although over many collections the bias is not important. An example of the calculations used to determine this correction factor may be found in Hackney (1977). Values reported here are the actual transport values although the corrected values are also reported for seasonal comparisons.

It is assumed in all the calculations that the current was uniform across the entire cross section of the creek, and that the concentration of suspended particulate material passing

the collecting station was uniform during the specified time interval and with respect to depth and width.

During the study, salinity, temperature and dissolved oxygen concentration of the water were measured *in situ* 20 cm below the surface every hour. Salinity was measured with a Yellow Springs S–C–T (salinity-conductivity-temperature) meter (Model 33), precise to ±0.7‰. Dissolved oxygen was measured with a Yellow Springs oxygen meter (Model 54), precise to ±1%. Temperature was measured with a thermister attached to the oxygen meter and precise to ±1%.

Three 1.22 $m^2$ pull-up traps (Higer and Kolipinski 1967) with 3.1 mm mesh were placed in the creek in March 1975. One net was installed along the south end of the creek approximately 22 m from the mouth, while the second and third traps were placed in the middle of the creek 70 and 92 m from the mouth. Collections were always made during ebbing tide at approximately the same water height during a tidal cycle as indicated by a permanent tidal gauge. One collection consisted of pulling each of the three nets on two successive days following the transport study. No reduction in catch was noted on the second day. These data provided information on the numbers and biomass of organisms in the creek during each transport study. A measure of the movement of organisms into and out of the creek was obtained by placing a 3.1 mm mesh bag seine across the entrance of the tidal creek. The bag stretched across the creek from the surface to the bottom. Organisms were removed during high slack tide and low slack tide. Although this technique was selective for smaller organisms (crabs and shrimp), it provided information on animal movements into and out of the creek.

#### *Suspended Particulate Material*

Water was collected 20 cm below the surface every 2 hours during each of 13 tidal periods from May 1975 to April 1976. The collection for January 1976 was made on February 5, 1976. Samples were collected from two consecutive semi-diurnal (12-hour) tidal periods on September 19 and 20, 1975, and one on February 5, 1976. Water was collected in 4-liter plastic jugs and preserved in 1% formalin solution to prevent agglutination and bacterial decomposition of the suspended particulate organic detritus. Preservation did not alter the analytical results since prior testing with preserved and unpreserved samples did not differ with respect to combustible carbon (ANOVA [analysis of variance] at $\alpha = 0.05$).

Water samples were brought to the laboratory and filtered through a Gelman Type A glass filter (0.3 $\mu$m porosity) following the procedure of Golterman (1969), with modification for the glass filters. The results are reported as the weight of oxidizable material (particulate organic detritus, POD) per liter of water and as the weight of nonoxidizable material (particulate inorganic detritus, PID) per liter of water. Golterman (1969) notes that the loss of bound water from clays in the PID is negligible. Appropriate corrections were made for the addition of formalin and for filter weight loss during ashing.

### RESULTS

#### *Transport*

The concentration of total suspended particulate material ranged from 4.6 to 119.4 mg/l. The oxidizable fraction, suspended POD, ranged from 1.5 to 19.7 mg/l while the PID ranged from 3.2 to 99.6 mg/l. Concentrations between 12.0 and 36.0 mg/l, 2.0 and 4.5 mg/l and 6.0 and 30.0 mg/l for total suspended material, organic fraction and inorganic fraction, respectively, were more common.

There was a net export of suspended POD during four of the 13 tidal periods and a net export of PID during five tidal periods (Table 1). Because of the variability in tidal flushing, the amount of suspended materials exchanged varied greatly from tidal cycles in which there was little net exchange to cycles in which more than 167 kg of suspended materials were exchanged (Table 1). The concentration of both POD and PID was always highest near low tide (Figure 2). Very little water exchange occurred during the lowest part of the tidal cycle. Incoming water filled only the tidal creek channel. Increased water flow and volume of water moving into or from the marsh occurred during the flood portion of the tidal cycle. Thus, actual exchange was determined more by concentrations of detritus at higher tide levels; for example, from 1500 to 2000 hours and from 0400 to 1200 hours (Figure 2) during the May 1975 sampling.

There was a total net flux of 39 kg of POD and 293 kg of PID into the marsh during the 13 tidal cycles studied. Most of the tides which exported detritus occurred during the summer, while detritus was imported during most of the rest of the year. There were 385 tidal cycles (Tide Tables 1975, 1976) during the 12-month study of detrital flux. Data from the 13 tidal cycles studied were integrated based on this information. More than 1164.5 kg of POD and 8662.8 kg of PID were estimated to have been added to the 5.84 ha area of marsh drained by the small tidal creek. This is equivalent to the addition of 168 g of detrital material per $m^2$ per year.

#### *Fauna*

Thirty-two species of fish and four invertebrate species were collected. The winter fauna was dominated by *Fundulus grandis* and *Fundulus confluentus.* During the spring and summer *Brevoortia patronus* and *Anchoa mitchilli* were very abundant. *Palaemonetes pugio* was present all year. For more details on the fauna of this area see Hackney (1977).

#### *Predictability*

The export or import of detritus depends on its concentrations in the water during the ebb and flood tide and on the difference between these two values, assuming equal water volume transport. Jackson (1964) found that

TABLE 1.

Summary of particulate detritus budget expressed as kilograms per tidal cycle.

| | Organic Particulate Transport | | | |
|---|---|---|---|---|
| Date | Out | In | Actual Net | Compensated Net |
| 5/27/75 | 46.603 | 31.931 | -14.670 | -14.786 |
| 6/28/75 | 25.839 | 6.587 | -19.252 | - 2.397 |
| 7/22/75 | 22.623 | 29.897 | + 7.274 | - 7.697 |
| 8/30/75 | 47.364 | 28.899 | -18.465 | -10.087 |
| 9/19/75 | 10.370 | 11.215 | + 0.845 | + 1.226 |
| 9/20/75 | 15.915 | 18.075 | + 2.160 | + 5.700 |
| 10/24/75 | 20.127 | 35.665 | +15.538 | +16.257 |
| 11/21/75 | 9.256 | 10.452 | + 1.196 | + 1.197 |
| 12/23/75 | 1.348 | 2.791 | + 1.443 | + 0.603 |
| 2/ 5/76 | 1.624 | 0.472 | - 1.152 | - 0.476 |
| 2/20/76 | 15.549 | 47.475 | +31.926 | - 1.528 |
| 3/26/76 | 16.529 | 25.283 | + 8.754 | + 8.603 |
| 4/16/76 | 28.846 | 52.579 | +23.733 | +41.833 |
| Totals | 261.993 | 301.321 | +39.328 | +38.440 |

| | Inorganic Particulate Transport | | | |
|---|---|---|---|---|
| Date | Out | In | Actual Net | Compensated Net |
| 5/27/75 | 112.641 | 101.406 | - 11.235 | - 10.978 |
| 6/28/75 | 55.158 | 16.759 | - 38.399 | + 2.761 |
| 7/22/75 | 53.289 | 75.456 | + 22.167 | - 7.926 |
| 8/30/75 | 123.850 | 54.815 | - 69.035 | - 53.386 |
| 9/19/75 | 26.237 | 31.950 | + 5.713 | + 6.793 |
| 9/20/75 | 35.980 | 49.358 | + 13.378 | + 23.367 |
| 10/24/75 | 61.199 | 96.547 | + 35.348 | + 38.563 |
| 11/21/75 | 41.367 | 37.393 | - 3.974 | - 3.974 |
| 12/23/75 | 4.069 | 9.313 | + 5.244 | + 2.052 |
| 2/ 5/76 | 4.393 | 1.403 | - 2.990 | - 1.063 |
| 2/20/76 | 42.664 | 178.980 | +136.316 | + 55.439 |
| 3/26/76 | 45.121 | 79.101 | + 33.980 | + 33.525 |
| 4/16/76 | 84.481 | 250.481 | +166.000 | +165.998 |
| Totals | 690.449 | 982.962 | +292.513 | +251.171 |

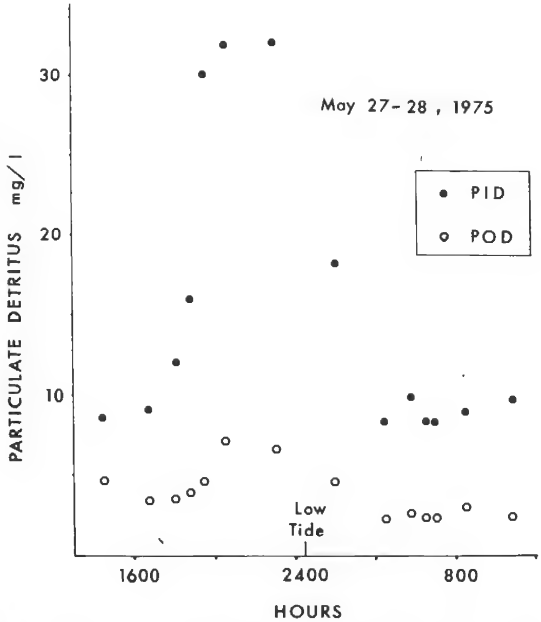


**Figure 2. Typical pattern of the concentration of particulate organic detritus (POD) and particulate inorganic detritus (PID) during a tidal cycle.**

temperature and tidal range affected the concentration of silt in English estuaries. A multiple regression analysis (Draper and Smith 1966) was used to determine the relationship of the dependent variable POD and the independent variables: temperature, salinity, dissolved oxygen, height of the water in the creek, tidal range, volume of water exported or imported during the day, biomass of organisms in the creek, number of these organisms, weight of plant debris moving in and out of the creek, time of day and time of year. This analysis was done separately for the ebb and flood tides. The analyses were repeated with PID as the dependent variable.

The relative importance of the variables was determined by a subset selection procedure (Hocking and Leslie 1967). This procedure selected tidal height as the most important variable which explained the variation of POD and PID. During ebb tide, eight variables explained 57.9% of the variability of the POD and 58.1% of the variability of the PID collected during ebb tide (Table 2). Salinity, dissolved oxygen, temperature, day of the year (a measure of seasonal variation) and number of organisms in the creek were also important variables in explaining the variability of POD and PID.

The number of organisms in the creek was also a significant factor in explaining some of the variability of detrital concentration (Table 2). Variable [7] was the biomass of organisms caught in one pull-up trap collection and variable [8] was the number of organisms caught in the same collection. Although these two variables were based on the same data collection they did not exhibit colinearity. Variable [6] was the number of organisms caught in the bag seine which is a measure of their abundance and movement within the creek. Seasonality (time of year), variable [5], was also important because more organisms were in the creek during certain times of the year (Hackney 1977). The influence of salinity, temperature and dissolved oxygen on detrital concentration may also occur when these factors interact with the faunal component of the creek and with the season.

When the same multiple regression analysis and subset selection procedures (using the same variables) were applied to the flood tide, no variable or combination of variables explained much of the variability of POD or PID. Erkenbrecher and Stevenson (1977) noted that ebb and flood

TABLE 2.

**Multiple regression model for the concentration of suspended particulate matter during ebb tide and relevant summary statistics.**

**Particulate Organic Detritus (POD)**

$$y = -1.1897 + 0.0011\,[5] + 0.01342\,[2] - 0.04927\,[4] + 0.10759\,[3] + 0.00766\,[1] + 0.00100\,[6] + 0.00167\,[7] - 0.00052\,[8]$$

| | |
|---|---|
| $r^2$ | = 0.5701 |
| mean square error | = 0.01996 |
| total sum of squares | = 2.5131 |
| number of observations | = 62 |

Variable order selected by subset selection procedure and the cumulative $r^2$ values.

| Variable | Cumulative |
|---|---|
| [1] | 0.1995 |
| [2] | 0.2418 |
| [3] | 0.3122 |
| [4] | 0.3920 |
| [5] | 0.4649 |
| [6] | 0.5336 |
| [7] | 0.5607 |
| [8] | 0.5791 |

**Particulate Nonorganic Detritus (PID)**

$$y = -6.527 + 0.006292\,[5] + 0.04668\,[2] - 0.1978\,[4] + 0.4340\,[3] + 0.0456\,[1] + 0.00948\,[9] + 0.00028\,[6] + 0.01082\,[7] - 0.00334\,[8]$$

| | |
|---|---|
| $r^2$ | = 0.6144 |
| mean square error | = 0.55018 |
| total sum of squares | = 14.1940 |
| number of observations | = 62 |

Variable order selected by subset selection procedure and the cumulative $r^2$ values.

| Variable | Cumulative |
|---|---|
| [1] | 0.3083 |
| [9] | 0.3601 |
| [4] | 0.3959 |
| [3] | 0.4212 |
| [5] | 0.4739 |
| [8] | 0.5811 |
| [7] | 0.5940 |
| [8] | 0.5811 |
| [7] | 0.5940 |

waters had distinctly different characteristics in a South Carolina tidal creek and that different biotic and abiotic factors were needed to explain the microbial concentration during ebb and flood tides.

The source of suspended particulate detritus appears to be the same for material in ebb and flood waters since no difference between the ratio of particulate organic detritus to total suspended material was noted. A simple linear regression applied to these combined data produced an $r^2$ of 0.952 for N = 135 (Figure 3). The resultant model (Y = 1.21 + 0.15874X, where Y is the POD and X is the total suspended material) provides a high degree of predictability. The organic material was 15.87% of the total during the study period no matter how high or low the total suspended concentration was in the water. Thus, the similarity of the predictive models for POD and PID is not surprising. The sediment on this marsh contains from 4.9 to 13.0% oxidizable material (Hackney and de la Cruz 1978) while the intact decaying plant material found on this marsh contains 68 to 93% oxidizable materials (Hackney 1977). This seems to indicate that the source of the suspended detrital material is not directly from decomposition of dead plant material. The similarity between the organic ratio of particulate material in the marsh sediment and that of the suspended detritus may indicate that the source of marsh sediment is primarily through the deposition of suspended material.

## DISCUSSION

Existing tidal transport studies of particulate organic detritus do not agree on either the net directional movement or on the percent of the overall vascular plant productivity in this movement. Estimates vary from near 50% net export

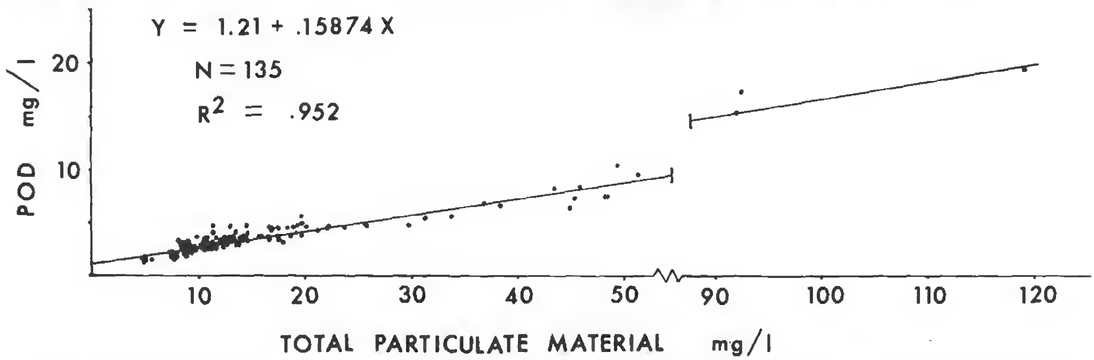


**Figure 3. Relationship of particulate organic detritus (POD) to total particulate material in the water between May 1975 – April 1976.**

to 6% net imports of particulate organic detritus. Nadeau (1972), Shisler (1975), Heinle and Flemer (1976), Woodwell et al. (1977) and the present study all reported net imports or at least no significant exports of suspended particulate organic detritus; while Teal (1962), de la Cruz (1965), Heald (1969), Day et al. (1973), Nixon and Oviatt (1973), Moore (1974), and Settlemyre and Gardner (1977) reported net exports. Some studies which reported high net exports are based on small data sets or on estimates rather than actual transport data. Only Moore's (1974) study, which reported net exports of 40% and 28% of the vascular productivity of two marsh systems, was based on the amount of data reported by Shisler (1975), Heinle and Flemer (1976), and Woodwell et al. (1977), who found net imports. No single factor (i.e., morphometry, hydrology, etc.) can explain the differences found between marshes with a net annual export and those with a net annual import of particulate organic detritus. All studies were made on tidal creeks except for Heald (1969) who studied a tidal river from which there was a constant supply of fresh water. Detrital export was expected in this system since there was a net export of water.

The concentration of particulate carbon in water has been determined by combustion (de la Cruz 1965; Heald 1969) and by analysis in a carbon analyzer (Moore 1974; Shisler 1975; Heinle and Flemer 1976; and Woodwell et al. 1977). Theoretically, there should be little difference between the two techniques. Because each of the references cited used the same technique throughout their study, net exports or imports cannot be attributed to differences in techniques.

Other studies (Day et al. 1973; Nixon and Oviatt 1973) report the flux only in terms of a predictive model, obtaining their values by subtracting all other potential pathways of energy loss from the total marsh productivity. This is a good approach, but until the role of the microbial community in marsh soils is quantified, this technique may overestimate the export.

Direct transport studies are deficient because they do not measure all of the tides during the year. The fewer tidal cycles examined, the greater the effect of one atypical tidal cycle on the annual budget. Conversely, the more tidal cycles examined (assuming random sampling), the more closely the estimates of total annual export or import approach the true value and the effect of one atypical day on the overall estimate is minimized. It is possible that some of these previous studies included data collected on atypical days or did not have a random sample of days including days when the weather was poor. When sampling was done on days preceded by fair weather, detrital export was observed in the study creek even though this is not what appears to be the usual pattern.

Another approach also provides strong evidence that tidal marshes do not export large amounts of organic material. In Georgia's estuaries, where a strong case is made by Odum and de la Cruz (1967) for a net tidal export of particulate detritus, Haines (1977) noted that the stable carbon isotope ratios of particulate detritus collected in Georgia estuaries did not resemble those of *Spartina alterniflora*. Stable isotopic ratios of *Spartina* carbon are different from the carbon ratios of phytoplankton or terrestrial detritus (Haines 1976). Carbon ratios of the plants are not changed to a significant extent as the carbon moves up the food chain and as it is degraded on the marsh (Haines 1977). The samples were collected from a tidal creek and a tidal river and were separated into five size fractions between 27 and 250 $\mu$m. The carbon ratios of all of these samples resembled those of organic matter of terrestrial or phytoplankton origin. Based on this and a mounting body of evidence from transport studies, Haines suggests a "re-examination of the assumption that the bulk of detrital carbon in Georgia's estuaries is derived from *S. alterniflora* production."

Examination of the sedimentary history of a marsh along with transport studies may be one of the best methods of determining long-term trends. The addition of 4.7 mm/yr organic material to the Flax pond marsh (Flessa et al. 1977) and estimates of the rate of sedimentation (Armentano and Woodwell 1975) substantiates Woodwell et al.'s (1977) contention that little carbon is exported from the Flax pond system. Another useful approach may be to examine the transport into and out of the entire estuarine system (Happ et al. 1977), as well as the transport from small creeks draining marshes. This approach requires information on the input of river systems which may be difficult to obtain.

More studies are needed to evaluate the dynamics and fate of suspended particulate detritus in the marsh-estuarine system. This study indicated that the amount of inundation of the marsh as reflected in the tidal height (variable [1] in Table 2), affected the particulate detritus concentration of water leaving the marsh. Therefore, differences in the amount of tidal inundation are suggested as an important factor with respect to particulate detritus transport reported in other studies. Tidal height was a measure of how much and to what extent the marsh was flooded. Tidal height does play a role in removing detritus from the water because marsh plants hinder or slow down the flow of water and produce conditions which may allow suspended material to leave the water column and settle on the substrate (Axelrad 1974). Once this material has settled, the current velocity necessary to resuspend the cohesive particles is greater than the current velocity necessary to transport these particles once they are in suspension. Particles smaller than 0.01 mm require as much current velocity to resuspend them as do particles over 2 mm (Hjulstrom 1939). The effect of the marsh biota may be important, particularly the filter feeders and amphipods as they remove detrital material from the water and deposit this as pseudofeces on the marsh. Many benthic amphipods also use detrital materials in the construction of their burrows (Thomas 1975). For this process to occur, water must reach these filter feeders, notably the

pelecypods *Polymesoda caroliniana* and *Geukensia demissus*, which live on the marsh. Fungi, bacteria and protozoa on the mud surface may be important in retaining detritus on the marsh once it has settled. Conversely, the larger invertebrates and fishes tend to stir up the sediment. The grass shrimp *Palaemonetes pugio* and killifish, *Fundulus* spp., were observed "muddying the water" on many occasions during this study. None of these biotic factors can affect the concentration of detritus in the water unless the marsh floods. Table 1 indicates the variation of transport due to the irregular flooding that is characteristic of Gulf coast marshes.

Factors affecting the particulate detrital concentration of the waters also affect the overall transport of particulate detritus. Amphipods were generally more abundant in tidal marshes during cooler months (Thomas 1975), while fishes and larger crustacea were less abundant. Most of the cooler months exhibited a pattern of net import of particulate detritus (Table 1). Conversely, exports occurred during summer months when the larger fauna were most abundant. The higher concentration of particulate detritus near low tide was probably due to the greater concentration of mobile organisms per unit of water. The warmer water temperatures also increased their activity.

Other environmental factors also play an important role. Redfield (1972) noted that sedimentary material may be carried onto the marsh due to strong winds stirring up sediment in nearby shallow areas. Strong winds produce these conditions in the nearby bay. Heavy rainfall in the nearby watershed thus increases the potential flow of material to the St. Louis Bay system by the Jourdan and Wolf rivers (Figure 1). Locally heavy rainfall during low tides could also increase the detritus load of bay waters. Presumably, imports of detritus onto the marsh are caused by an increased amount of river-borne detritus in the water surrounding the marsh system.

Redfield (1972) suggested that marshes along the eastern coast of the United States are building up at the rate of 2.5 mm/yr. This requires the addition of material. The marsh in the present study appears to have a long-term record of clastics and organic material accumulation as evidenced by recognizable *Spartina* rhizomes buried 20 to 40 cm below the surface of the *Juncus* marsh. *Spartina* is characteristic of lower areas of this marsh (de la Cruz and Hackney 1977).

While it is possible to predict the concentration of particulate detrital material in the water that comes from marshes during ebb tide, based on information on tidal height, physical conditions of the water in the creek, time of the year and the abundance of organisms within the creek, the prediction of the concentration of particulate organic detritus in the water during flood tide is impossible. It probably depends greatly on the configuration and current patterns of the nearby estuaries and on such random factors as weather conditions and nearby river discharge.

This investigation suggests a net import of particulate material onto the marsh. Thus, it appears that high vascular plant productivity may not be the most important function of the marsh relative to the overall productivity of the estuarine system. Net export of particulate material occurs somewhat infrequently and is probably occasioned primarily by low concentrations of particulate detritus in the surrounding bodies of water. The marsh may serve as a holding area for material discharged by rivers, importing material during high river discharge periods and exporting material when that discharge is small. Thus, marshes may act as a control mechanism by removing materials from the water when the concentration of these materials is high in the nearby bays and rivers and then exporting these same materials when the concentration is low. The marshes, then, may dampen oscillations in the concentration of suspended materials in nearby bodies of water. This would tend to produce a more even release of material to offshore waters. Thus, even if a marsh exports very little of its own production as suspended particulate matter, it may be important in the regulation of overall export of material from estuaries.

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Gulf Research Reports

Volume 6 | Issue 3

January 1979

# An Annotated Key to the Mysidacea of the North Central Gulf of Mexico

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DOI: 10.18785/grr.0603.03



Recommended Citation

Stuck, K. C., H. M. Perry and R. W. Heard. 1979. An Annotated Key to the Mysidacea of the North Central Gulf of Mexico. Gulf Research Reports 6 (3): 225-238.

Retrieved from http://aquila.usm.edu/gcr/vol6/iss3/3

*Gulf Research Reports*, Vol. 6, No. 3, 225–238, 1979.

# AN ANNOTATED KEY TO THE MYSIDACEA OF THE NORTH CENTRAL GULF OF MEXICO

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*ABSTRACT* An annotated key is provided to 17 species in 11 genera of the order Mysidacea from the north central Gulf of Mexico. All species are illustrated. The occurrence of *Bowmaniella dissimilis* is reviewed in light of Holmquist's (1975) renaming of *B. dissimilis sensu* Brattegard (1970). Reports of several species of *Metamysidopsis* are discussed. The possible hybridization of two species of *Taphromysis* is considered.

## INTRODUCTION

With the exception of the decapod crustaceans, few comprehensive keys exist to the estuarine and marine invertebrate fauna of the north central Gulf of Mexico. Expansion of research efforts in the fields of ecology, fisheries biology and toxicology have increased the need for basic systematic reviews of many invertebrate groups. The authors intend to publish a series of illustrated keys to selected groups of Crustacea that will facilitate identification of local fauna. All descriptions and illustrations in the following key represent original work, with the exception of Figure 1.

Peracaridans of the order Mysidacea are small shrimp-like organisms found in a variety of habitats. They may be part of the benthos, meroplankton or holoplankton, but most are typically hypoplanktonic. The majority of the species are neritic, with both freshwater and marine representatives known.

A side and dorsal view of a typical mysid is illustrated in Figure 1. The thorax is covered by a carapace which is not united with the last four thoracic segments. The first thoracic segment is united with the head. Anteriorly, the carapace may project into a rostrum. The antennules are biramous. The antenna has a large scale-like exopod. The eyes are usually stalked, but in the genus *Pseudomma*, they are fused into an ocular plate that extends across the anterior margin of the carapace. The mouthparts consist of a pair of mandibles and two pairs of maxillae.

The first, and occasionally the second, pair of thoracic appendages may be modified as maxillipeds. The six or seven remaining thoracic appendages are biramous with filamentous exopods that sometimes bear swimming setae; some may have subchelate endopods. In the females, two or three

Manuscript received July 26, 1979; accepted August 16, 1979.

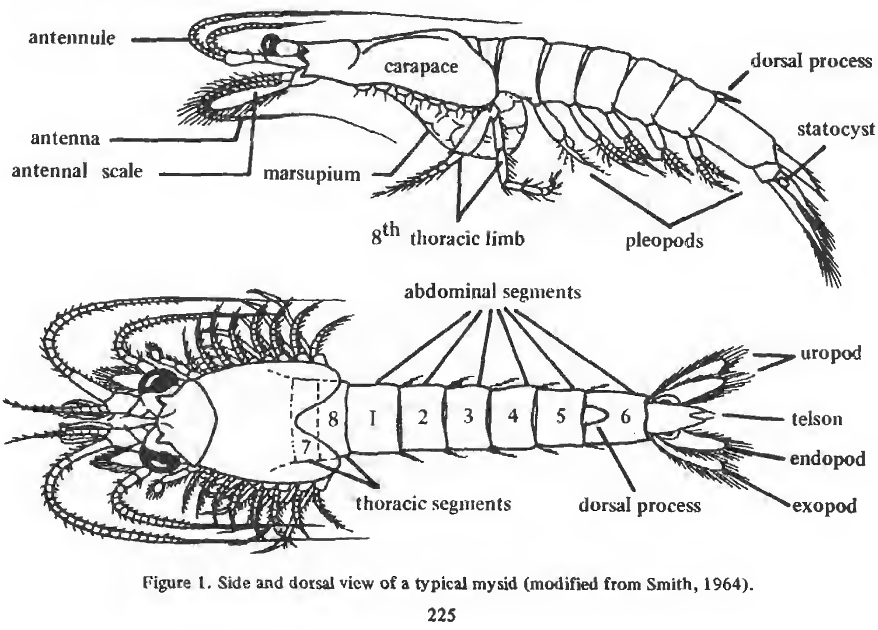


Figure 1. Side and dorsal view of a typical mysid (modified from Smith, 1964).

pairs of oostegites form a subthoracic marsupium to brood eggs.

Mysids are sexually dimorphic. The abdominal appendages or pleopods are rudimentary in females and developed in males. In the genus *Bowmaniella* these abdominal appendages are distinctive, with the third pleopod of the male bearing a large, complex copulatory organ.

A pair of biramous uropods are located on either side of the telson, with the inner ramus bearing a bead-like statocyst.

Many mysidaceans are filter feeders and some species use the second maxilla to produce a current and trap food; others are carnivores. A few forms are scavengers.

Neritic and marine species often occur in large swarms and provide valuable forage for many fish.

To date, about 460 species have been reported throughout the world.

## KEY TO THE MYSIDACEA OF THE NORTH CENTRAL GULF OF MEXICO

1. Eyes fused, forming a large ocular plate extending across anterior margin of carapace (Fig. 2e). . . . . . . . . . . . . . . . *Pseudomma* sp. (Page 233)

   Eyes not fused into an ocular plate, supported on separate eyestalks . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .2

2. Distal end of telson emarginate (slightly indented), concave or deeply cleft (Fig. 5a–d, g, i, k, l, p–s) . . . . . . . . . .3

   Distal end of telson convex, linguiform in appearance, without terminal cleft or emargination (Fig. 5f, h, j, m–o) . . . 11

3. Antennal scale with lateral tooth present (though sometimes minute), devoid of setae on outer margin (Fig. 3a–d, f) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .4

   Antennal scale without lateral tooth, setae present on both inner and outer margins (Fig. 3g,i,k,o–q) . . . . . . . . . .6

4. Each apical lobe of telson armed with 1 large spine (Fig. 5a); antennal scale small and rounded in appearance; sympod of antennal peduncle with large barbed projection on its inner distal corner (Fig. 3a) . . . . *Anchialina typica* (Page 227)

   Each apical lobe of telson armed with 2 large spines (Fig. 5b–d); antennal scale of moderate size, more elongate; sympod of antennal peduncle without large barbed projection on its inner distal corner . . . . . . . . . . . . . . . . . . . .5

5. Posterior margin of fifth abdominal segment with dorsal process (Fig. 1); outer uropod armed with 18 or more lateral spines; inner uropod armed with 5 or more large spines along medial margin, without small spines near statocyst (Fig. 4c, d). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Bowmaniella* spp. (Page 232) (*Bowmaniella brasiliensis* and *Bowmaniella floridana*)

   Posterior margin of fifth abdominal segment without dorsal process; outer uropod armed with 16 or less lateral spines; inner uropod armed with 3 or 4 large spines along medial margin, 5 to 7 small spines near statocyst (Fig. 4b) . . . . *Bowmaniella portoricensis* (Page 227)

6. Terminal cleft or emargination devoid of spines on its inner margins (Fig. 5g, k, l) . . . . . . . . . . . . . . . . . . . . . . .7

   Terminal cleft or emargination armed with spines or laminae (flat spine-like projections) (Fig. 5i, p–s) . . . . . . . . .8

7. Proximal one fourth of lateral margin of telson unarmed; terminal cleft moderately deep (Fig. 5g) . . . . . . . . . . . . . *Promysis atlantica* (Page 234)

   Entire lateral margin of telson armed with spines; distal end with shallow emargination between large inner pair of spines (Fig. 5k, l). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Mysidopsis furca* (Page 235)

8. Lateral margin of telson armed with 8 to 20 spines (Fig. 5p–s) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .9

   Lateral margin of telson armed with 25 or more spines (Fig. 5i) . . . . . . . . . . . . *Bathymysis renoculata* (Page 235)

9. Proximal half of lateral margin of telson devoid of spines (Fig. 5p); inner uropod bearing 15 or more spines along medial margin (Figure 4o). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Heteromysis formosa* (Page 237)

   Entire margin of telson bearing spines (Fig. 5q–s); inner uropod bearing 1 spine along medial margin (Fig. 4p–r). . . . 10

10. Anterior margin of carapace with small lateral spine just below base of eyestalk (Fig. 2p) . . . . . . . . . . . . . . . . . . . *Taphromysis louisianae* (Page 237)

Anterior margin of carapace without lateral spine (Fig. 2q) . . . . . . . . . . . . . . . *Taphromysis bowmani* (Page 237)

11. Antennal scale with lateral tooth (Fig. 3f); terminal portion of telson armed with several large spines on each lateral corner and 3 very small spines medially (Fig. 5f) . . . . . . . . . . . . . . . . . . . . . . . . *Siriella thompsonii* (Page 234)

Antennal scale without lateral tooth (Fig. 3h, j, l–n); apex of telson variously armed with 2 or more spines (Fig. 5h, j, m–o) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12

12. Antennal scale more than 12 times long as wide (Fig. 3n); distal half of telson armed with 40 or more spatulate spines (Fig. 5o) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Brasilomysis castroi* (Page 236)

Antennal scale 8 or less times long as wide (Fig. 3h, j, l, m); lateral margins of telson armed with nonspatulate spines (Fig. 5h, j, m, n) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13

13. Proximal two thirds of lateral margins of telson devoid of spines; apex armed with 1 pair of spines slightly longer than laterals (Fig. 5h). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Metamysidopsis swifti* (Page 234)

Entire lateral margin of telson armed with spines; apex armed with 2 or more pairs of spines distinctly longer than laterals (Fig. 5j, m, n). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 14

14. Apex of telson armed with 8 or more long spines (Fig. 5m, n); inner uropods with 3 or less (rarely 4) spines near statocyst (Fig. 4l, m) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15

Apex of telson armed with 6 or less long spines (Fig. 5j); inner uropods with 4 or more spines near statocyst (Fig. 4j) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Mysidopsis bigelowi* (Page 235)

15. Apex of telson with 12 to 16 long spines gradually increasing in length to the midline (Fig. 5n); inner uropod with 1 spine near statocyst (Fig. 4m) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Mysidopsis almyra* (Page 236)

Apex of telson with 8 to 12 long spines abruptly increasing in length to the midline (Fig. 5m); inner uropod with 2 or more spines near statocyst (Fig. 4l). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *Mysidopsis bahia* (Page 236)

## *ANCHIALINA TYPICA* (KRØYER, 1861)

### *Description*

*Carapace* – Rectangular in appearance, anterior dorsal margin a broad rostral plate, the distal end appearing flat and covering entire base of eyestalks. Posterior dorsal margin slightly concave, covering all thoracic segments (Figure 2a).

*Antennal peduncle and scale* - Scale very small, about 1.8 times as long as wide at its midlength, rhomboidal in appearance; lateral margin straight, devoid of setae, ending in minute tooth; apex and inner margin broadly rounded, bearing setae, distal tip with faint suture. Second segment of peduncle massive, about 3.5 times as long as third segment and 1.2 times as long as scale. Inner distal margin of sympod with long curved projection bearing barbs on inner margin, outer distal corner with small tooth (Figure 3a).

*Uropods* – Exopods about 0.8 times as long as telson and slightly shorter than endopods; lateral margins usually bearing a row of about 18 spines, increasing in length to the larger inwardly curved distal spines, setae present along inner margin. Endopods slightly longer than telson, bearing patterned row of 45 to 50 spines of variable length, the distal 2 spines being longest, both inner and outer margins bearing setae (Figure 4a).

*Telson* – Rather long, about 2.7 times maximum width; distal end with deep cleft bearing 30 to 40 slender laminae, increasing in length to apical lobes; lateral margins straight, distal one fourth curving slightly inward, proximal one fifth unarmed, remainder bearing 25 to 35 spines of variable length which tend to be more concentrated and longer distally; each apical lobe bearing 1 large straight spine (Figure 5a).

*Other characters* – General appearance distinctly stout and robust. Integument covered with many minute hairs concentrated on dorsal surfaces of antennae, uropods and telson. First pair of pleopods in males uniramous, all others biramous. Third male pleopod with long 11-segmented exopod bearing modified setae. All pleopods of females reduced to uniramous plates.

*Length* – Adult males to 5.8 mm and females to 5.0 mm.

*Ecology* – Polyhaline, hypoplanktonic.

## *BOWMANIELLA PORTORICENSIS* BĂCESCU, 1968

### *Description*

*Carapace* – Anterior dorsal margin a long, slender, acutely pointed rostrum descending somewhat between the eyes and reaching cornea. Posterior dorsal margin deeply concave,

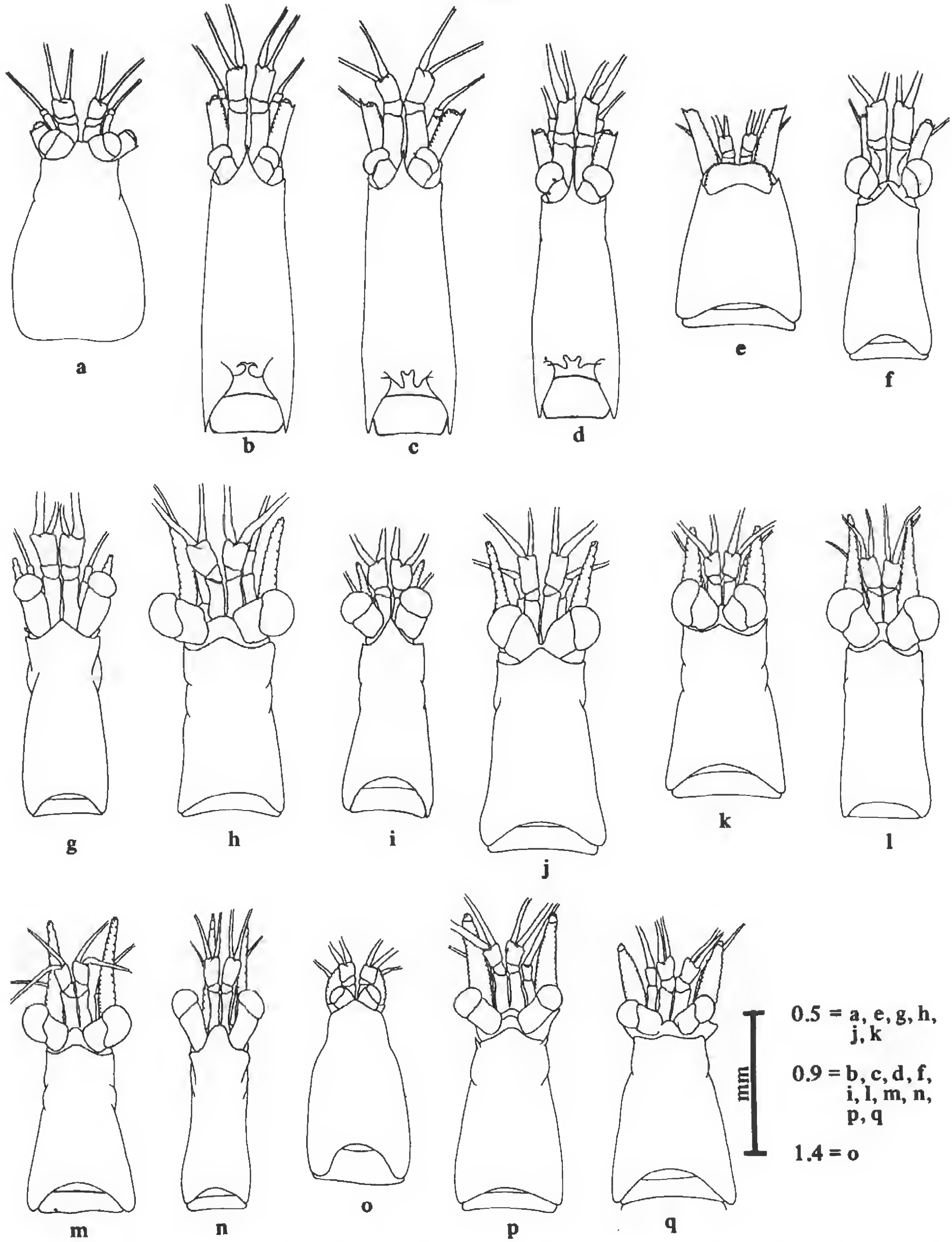


Figure 2. Carapace: (a) *Anchialina typica*, (b) *Bowmaniella portoricensis*, (c) *Bowmaniella floridana*, (d) *Bowmaniella brasiliensis*, (e) *Pseudomma* sp., (f) *Siriella thompsonii*, (g) *Promysis atlantica*, (h) *Metamysidopsis swifti*, (i) *Bathymysis renoculata*, (j) *Mysidopsis bigelowi*, (k) *Mysidopsis furca*, (l) *Mysidopsis bahia*, (m) *Mysidopsis almyra*, (n) *Brasilomysis castroi*, (o) *Heteromysis formosa*, (p) *Taphromysis louisianae*, (q) *Taphromysis bowmani*.

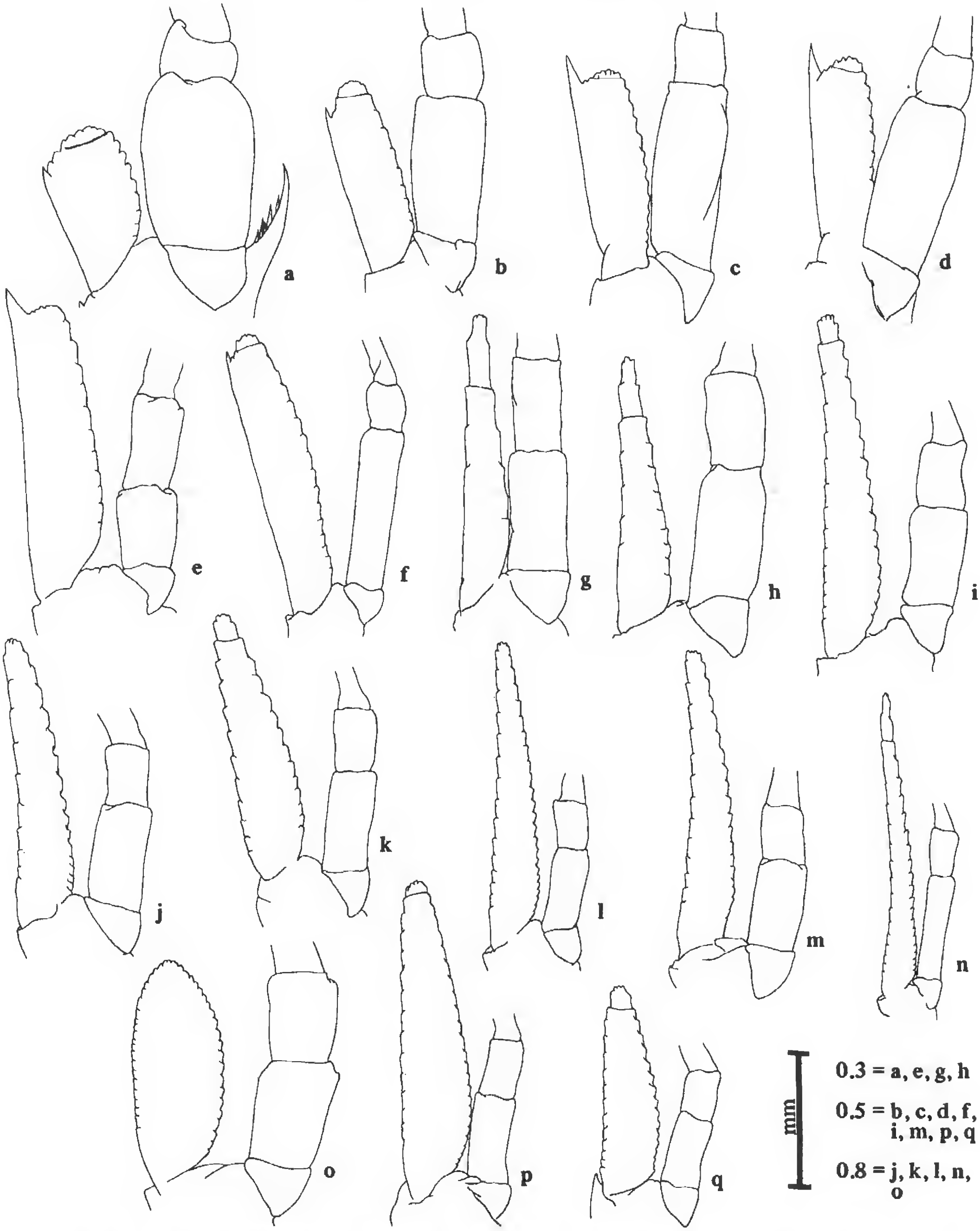


Figure 3. Antennal peduncle and scale: (a) *Anchialina typica*, (b) *Bowmaniella portoricensis*, (c) *Bowmaniella floridana*, (d) *Bowmaniella brasiliensis*, (e) *Pseudomma* sp., (f) *Siriella thompsonii*, (g) *Promysis atlantica*, (h) *Metamysidopsis swifti*, (i) *Bathymysis renoculata*, (j) *Mysidopsis bigelowi*, (k) *Mysidopsis furca*, (l) *Mysidopsis bahia*, (m) *Mysidopsis almyra*, (n) *Brasilomysis castroi*, (o) *Heteromysis formosa*, (p) *Taphromysis louisianae*, (q) *Taphromysis bowmani*.

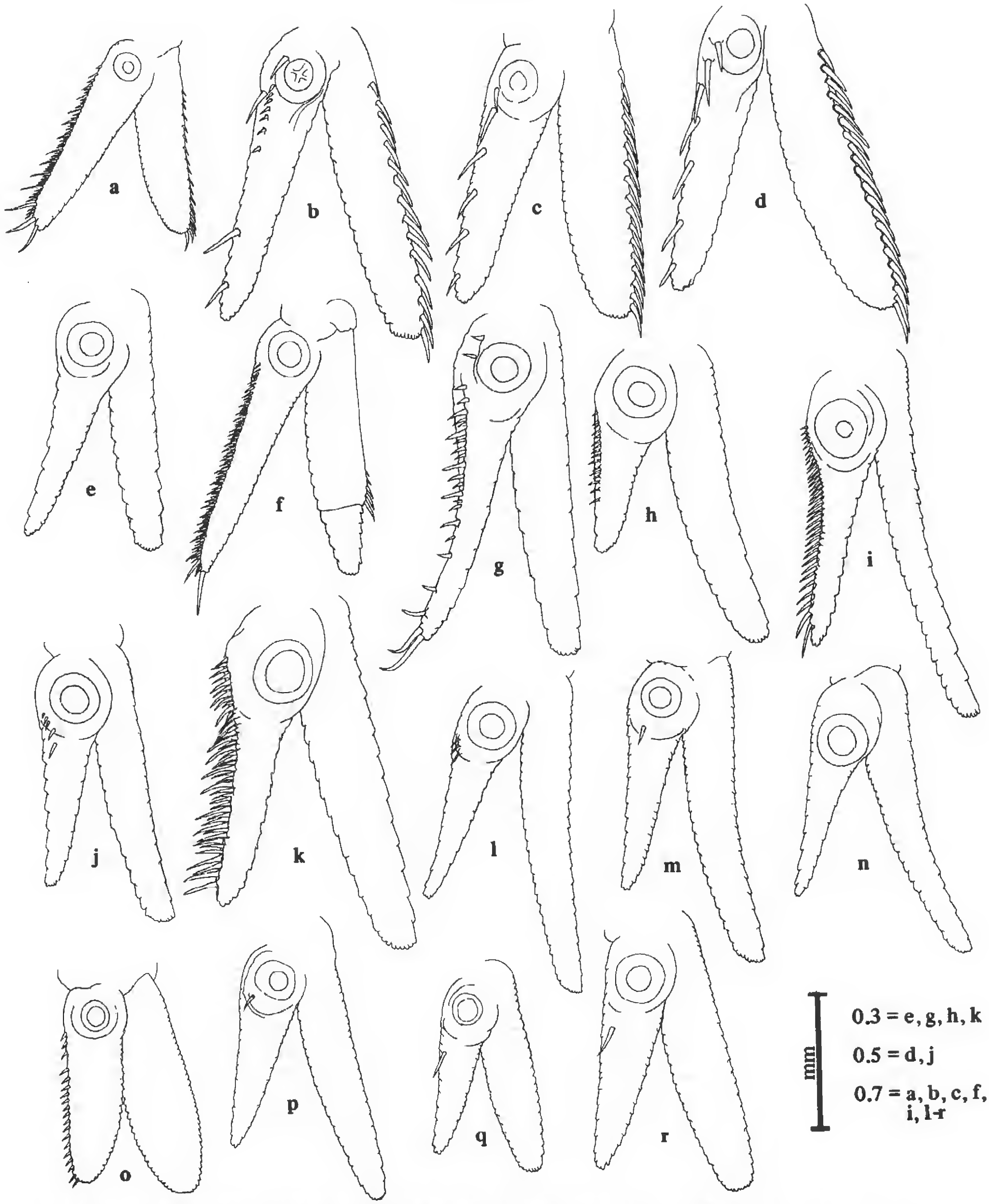


Figure 4. Uropod: (a) *Anchialina typica*, (b) *Bowmaniella portoricensis*, (c) *Bowmaniella brasiliensis*, (d) *Bowmaniella floridana*, (e) *Pseudomma* sp., (f) *Siriella thompsonii*, (g) *Promysis atlantica*, (h) *Metamysidopsis swifti*, (i) *Bathymysis renoculata*, (j) *Mysidopsis bigelowi*, (k) *Mysidopsis furca*, (l) *Mysidopsis bahia*, (m) *Mysidopsis almyra*, (n) *Brasilomysis castroi*, (o) *Heteromysis formosa*, (p) *Taphromysis louisianae*, (q) *Taphromysis bowmani*, (r) *Taphromysis bowmani*, intermediate form.

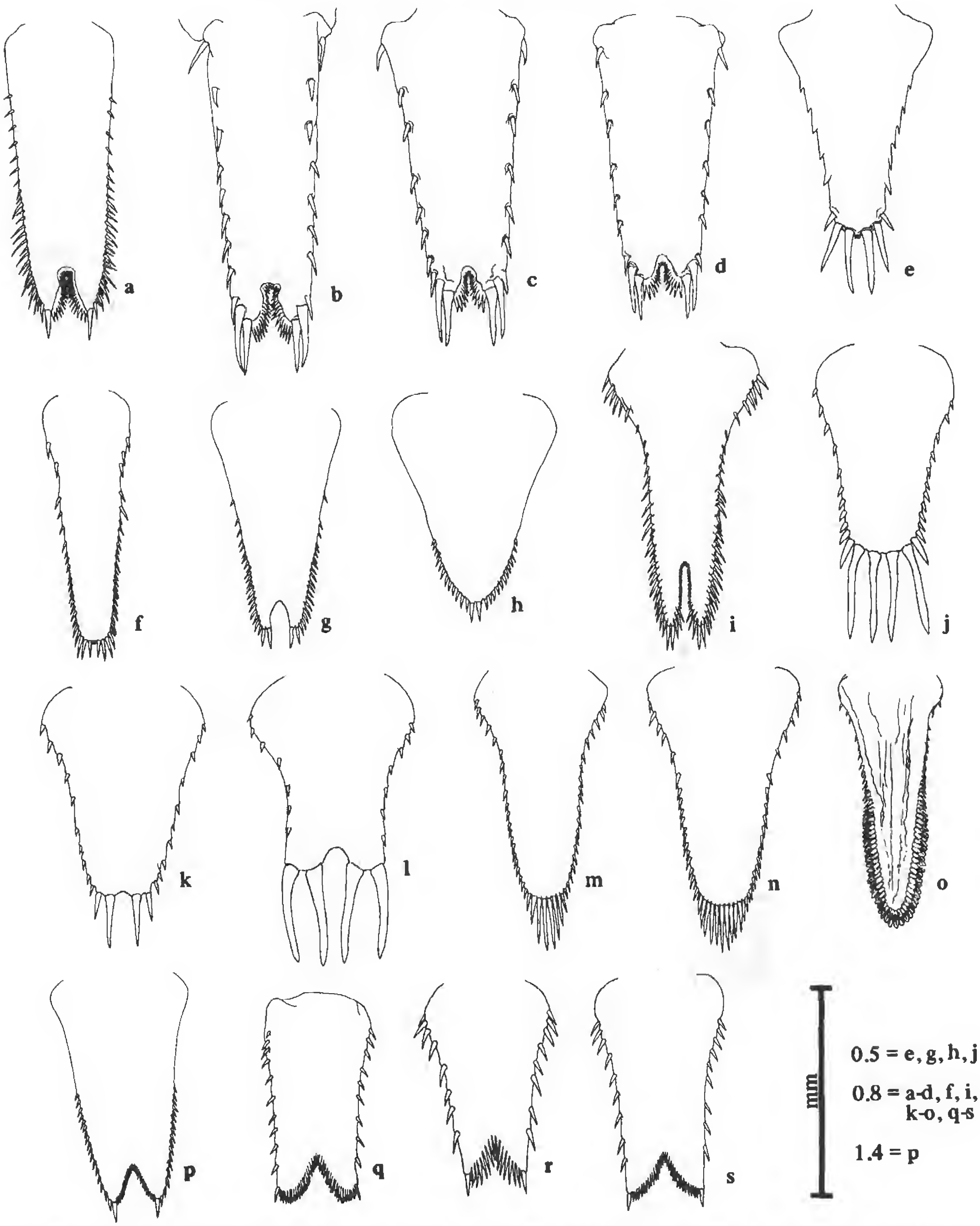


Figure 5. Telson: (a) *Anchialina typica*, (b) *Bowmaniella portoricensis*, (c) *Bowmaniella floridana*, (d) *Bowmaniella brasiliensis*, (e) *Pseudomma* sp., (f) *Siriella thompsonii*, (g) *Promysis atlantica*, (h) *Metamysidopsis swifti*, (i) *Bathymysis renoculata*, (j) *Mysidopsis bigelowi*, (k) *Mysidopsis furca*, male, (l) *Mysidopsis furca*, female, (m) *Mysidopsis bahia*, (n) *Mysidopsis almyra*, (o) *Brasilomysis castroi*, (p) *Heteromysis formosa*, (q) *Taphromysis louisianae*, (r) *Taphromysis bowmani*, (s) *Taphromysis bowmani*, intermediate form.

bearing 2 oval-shaped lobes that form a slight sulcus, seventh and eighth thoracic segments exposed dorsally (Figure 2b).

*Antennal peduncle and scale* — Scale about 3.2 times as long as wide at its midlength, faint suture separating distal tip of apex; lateral margin devoid of setae, ending in small distal tooth not extending beyond apex of scale; inner margin and apex setose. Third segment of peduncle about 0.4 times as long as second; entire peduncle about 1.3 times as long as scale (Figure 3b).

*Uropods* — Exopods subequal in length with endopods bearing a row of 13 to 16 large spines on outer margin, inner margin setose. Inner margin of endopods bearing 3 or 4 large spines extending from area of statocyst to distal tip; row of 5 to 7 small spines extending distally from inner margin of statocyst; both inner and outer margins setose (Figure 4b).

*Telson* — Cleft and rectangular in appearance, about 3.0 times as long as wide at its midlength; lateral margins nearly straight, bearing 6 to 9 spines; each apical lobe with a pair of large spines. Terminal cleft relatively deep, about 0.14 times total length of telson, each inner margin bearing 14 to 17 spinules (Figure 5b).

*Other characters* — Third pleopod of male bearing a large, complex copulatory organ on its distal end. All pleopods of females reduced to uniramous plates.

*Remarks* — The copulatory organ is similar to that of *B. floridana* in having a large striated lobe distally, but lacks the membranous accessory lobe. This species is easily distinguished from *B. brasiliensis* by the lack of the hook-like terminal apophysis and the presence of a striated lobe distally.

The illustrations and description presented here are in general agreement with the original description by Băcescu (1968) with some exceptions. Băcescu reported the number of lateral spines on the telson to be 7 for females and 4 to 5 for males. Females examined by the authors from the northern Gulf of Mexico have 7 to 9 lateral spines on the telson, males 6 to 7. The depth of the terminal cleft was also slightly less in our specimens.

*Length* — Mature males to 9.0 mm and females to 11.0 mm.

*Ecology* — Hypoplanktonic, streamlined modified body adapted for burrowing in sand substrates. Polyhaline, not known from estuarine habitats.

### *BOWMANIELLA* SPP.

Reliable separation of *B. floridana* and *B. brasiliensis* is based on the structure of the distal complex of the male third pleopod. Females and immature males of these two species are, for all practical purposes, impossible to separate and are therefore treated together in the following description.

#### *Description*

*Carapace* — Anterior dorsal margin a long, slender, acutely pointed rostrum extending to cornea of eye. Posterior dorsal margin deeply concave, forming an M-shaped sinus with 1 small median and 2 larger lateral lobes, seventh and eighth thoracic segments exposed dorsally (Figure 2c, d).

*Antennal peduncle and scale* — Scale about 3.5 times as long as wide at its midlength, faint suture separating distal tip of apex; lateral margin devoid of setae, ending in large distal tooth extending well beyond apex of scale; inner margin and apex setose. Third segment of peduncle about 0.3 times as long as second segment; entire peduncle equal to or slightly longer than scale (Figure 3c, d).

*Uropods* — Exopod about 1.2 times as long as endopod and bearing row of about 15 to 21 strong, evenly spaced spines along lateral margin; inner margin setose. Inner margin of endopod bearing 4 to 7 large spines extending from area of statocyst to distal tip; both inner and outer margins setose (Figure 4c, d).

*Telson* — Cleft and rectangular in appearance, about 2.7 times as long as wide at its midlength; lateral margins nearly straight, bearing 6 to 8 spines; each apical lobe bearing 1 pair of large spines. Depth of cleft about 0.12 times entire length of telson, each inner margin with about 12 to 15 spinules (Figure 5c, d).

*Other characters* — Posterior dorsal margin of fifth abdominal segment with articulated process (Figure 1) in both *Bowmaniella floridana* and *B. brasiliensis*, this process lacking in *B. portoricensis*.

### *BOWMANIELLA FLORIDANA* HOLMQUIST, 1975

#### *Description*

*Third pleopod of male* — Copulatory organ large and complex. Terminal lobular complex composed of a large striated lobe and a smaller accessory lobe. Outer stylet slightly curved, smooth and pointed. Apical claw slightly curved, indented, bearing a row of curved spines. Para-apical claw also curved, laminated and bearing many spines (Figure 6).

*Remarks* — Brattegard (1970) included the northern Gulf of Mexico in the known range for *B. dissimilis* (Coifmann, 1937). Holmquist (1975) stated that Brattegard's illustrations are of specimens which do not belong to *B. dissimilis*, but to a new species, *B. floridana*. Examination of a large number of specimens of this type from the northern Gulf of Mexico revealed agreement with Holmquist's *B. floridana* (= *B. dissimilis sensu* Brattegard, 1970) with one exception. Brattegard stated, "bow absent" from male copulatory organ and Holmquist made no mention of such a bow. All specimens of *B. floridana* from the present study clearly possess a bow (Figure 6). Either Brattegard overlooked the bow or the specimens illustrated herein represent a new species. These differences are currently under investigation by Thomas E. Bowman of the United States National Museum.

*Gastrosaccus dissimilis* Coifmann, 1937, was originally described off the coast of Brazil between Pernambuco and

Rio de Janeiro. Brattegard (1970) considered *Bowmaniella dissimilis* conspecific with both *Gastrosaccus dissimilis* and *Bowmaniella (Coifmanniella) dissimilis sensu* Băcescu, 1968. Tattersall (1951) reported *G. dissimilis* from the Louisiana Gulf coast; however, his illustration of the male third pleopod (fig. 29, p. 97) differs greatly from that of Coifmann (1937)(fig. 3c, p. 7). While Tattersall's illustration lacks detail, it is very similar to the male third pleopod of our specimens of *B. floridana* (Figure 6). No specimens of *B. dissimilis* were identified from our samples, suggesting that previous records for this species in the study area may be *B. floridana*. Bowman (personal communication) indicated that many published records of *B. dissimilis* are probably *B. floridana;* however, a reexamination of these specimens will be necessary to validate this assumption.

*Length* – Adult males to 8.0 mm and females to 10.0 mm.

*Ecology* – Hypoplanktonic, common in estuarine waters.

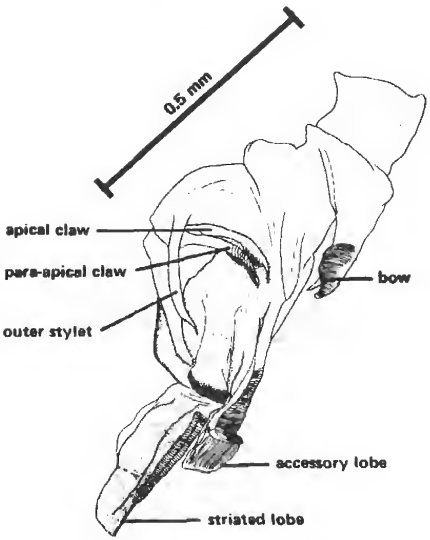


**Figure 6. Copulatory organ, *B. floridana*.**

*BOWMANIELLA BRASILIENSIS* BĂCESCU, 1968

*Description*

*Third pleopod of male* – Copulatory organ smaller than that of *B. floridana,* lacking a large terminal lobular complex. Terminal apophysis descending from a hook-like seizing device. Inferior stylet developed into a long membranous lamina. Para-apical claw strongly curved upward, lower margin indented and bearing a row of slender spines. Apical claw long, slender and curving downward, bearing a few scattered spines (Figure 7).

*Remarks* – Băcescu (1968) has referred to Coifmann's (1937) illustration of the male third pleopod (fig. 3c, p. 7) of *Gastrosaccus dissimilis* as being somewhat similar to his drawing (fig. 6d, p. 366) of *B. brasiliensis*. Coifmann's illustration clearly shows a slender apical claw which curves downward, an upward curving para-apical claw and a terminal apophysis. These structures are also in general agreement with Băcescu's detailed illustration (fig. 5b, p. 364) of the male copulatory organ; however, the identification of the para-apical and apical claw were apparently reversed. The taxonomic status of *B. brasiliensis* should be examined in light of these similarities.

*Bowmaniella brasiliensis* is a fairly common species, often taken with *B. floridana*. The lack of published reports of this species from other Gulf states'suggests that it may have been included under the name *B. dissimilis*.

*Length* – Adult males to 8.0 mm and females to 10.0 mm.

*Ecology* – Hypoplanktonic, common in estuarine waters.

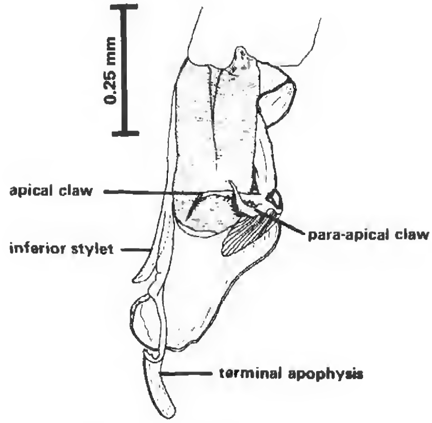


**Figure 7. Copulatory organ, *B. brasiliensis*.**

*PSEUDOMMA* SP.

*Description*

*Carapace* – Rectangular in appearance, lacking rostrum. Eyes fused, forming an ocular plate extending across anterior margin of carapace. Posterior dorsal margin strongly concave, exposing seventh and eighth thoracic segments (Figure 2e).

*Antennal peduncle and scale* – Scale with setae along inner margin, outer margin lacking setae and terminating in large tooth. Third segment of peduncle about 1.2 times as long as second segment, extending two thirds of the distance along scale (Figure 3e).

*Uropods* – Exopods about 1.25 times as long as telson, subequal in length to endopods. Both endopods and exopods bearing setae along inner and outer margins, devoid of spines (Figure 4e).

*Telson* – Linguiform, entire, about 3.0 times as long as wide at its midlength; apex armed with 2 pairs of large spines, smaller pair laterally; lateral margins with 5 to 7 sharply pointed serrations (Figure 5e).

*Remarks* – The species appears to be undescribed. Specimens do not key to any of the recognized species of *Pseudomma* (Bowman, personal communication). Description awaits collection of male specimens.

### *SIRIELLA THOMPSONII* (H. MILNE–EDWARDS, 1837)

#### *Description*

*Carapace* – Anterior dorsal margin an acutely pointed rostral plate, partly covering the base and extending between eyestalks. Posterior margin concave, loose, exposing eighth and part of seventh thoracic segments (Figure 2f).

*Antennal peduncle and scale* – Scale about 5.5 times as long as wide at its midlength; lateral margin straight, devoid of setae, ending in tooth; apex rounded, extending past lateral tooth; inner margin and apex setose. Second segment of peduncle long and slender, about 4.0 times as long as third segment; entire peduncle about 0.8 times as long as scale (Figure 3f).

*Uropods* – Exopods about 1.2 times as long as telson and slightly shorter than endopods; proximal three fourths of lateral margin devoid of setae and separated from distal one fourth by suture, a row of 3 to 6 graduated spines, increasing in length distally, located anterior to suture; outer margin of distal segment and entire inner margin setose. Endopod bearing row of about 70 spines of unequal size and irregular arrangement, extending from statocyst to apex, which bears a single large spine; both inner and outer margins setose (Figure 4f).

*Telson* – Slender, about 2.8 times as long as maximum width; distal end rectangular in appearance, armed with 3 pairs of long spines on corners, 3 much smaller spines and a pair of plumose setae medially; lateral margins nearly straight, except for slightly concave area along proximal one third; about 25 spines of variable size and spacing extend from about proximal one fifth to distal end (Figure 5f).

*Other characters* – Endopods of thoracic limbs elongate, terminating in "brush" of stiff setae. First pleopod of male with well-developed exopod and a bi-lobed (pseudobranchial) process, lacking a well-developed endopod. Pleopods 2 through 5 with both exopods and endopods well-developed and bearing coiled, bi-lobed pseudobranchiae. All pleopods of females reduced to uniramous plates.

*Length* – Adult males to 6.5 mm and females to 5.7 mm.

*Ecology* – Polyhaline, planktonic.

### *PROMYSIS ATLANTICA* TATTERSALL, 1923

#### *Description*

*Carapace* – Anterior dorsal margin a broad, bluntly pointed rostral plate which covers and extends past base of eyestalks. Posterior dorsal margin concave, exposing eighth and part of seventh thoracic segments (Figure 2g).

*Antennal peduncle and scale* – Scale about 8.0 times as long as wide at its midlength, bearing a few setae along both margins, lacking a lateral tooth; distal one fourth divided from remainder of scale by a suture. Third segment of peduncle about 0.7 times as long as second segment; entire peduncle about 0.8 times as long as scale (Figure 3g).

*Uropods* – Exopods about 1.8 times as long as telson and slightly longer than endopods, setose along both margins. Endopods curving inward toward telson, inner margin bearing a row of about 24 spines of variable size and spacing extending from statocyst to distal tip; apex bearing 2 strong curved spines, much longer than others; both inner and outer margins setose (Figure 4g).

*Telson* – About 1.8 times as long as maximum width, terminal notch devoid of setae or spines; lateral margins relatively straight, devoid of spines on proximal one fourth, distal three fourths armed with 18 to 23 spines of about equal size; each apical lobe with 2 spines, slightly longer than lateral spines (Figure 5g).

*Other characters* – General body form slender, abdomen appears very elongate with sixth segment twice as long as fifth segment. Pleopods of males biramous, endopod of pleopod 1 rudimentary, exopod of pleopod 4 bearing a long barbed seta. All pleopods of females reduced to uniramous plates.

*Length* – Adult males and females to 8.0 mm.

*Ecology* – Polyhaline, planktonic, sometimes found in large aggregations.

### *METAMYSIDOPSIS SWIFTI* BĂCESCU, 1969

#### *Description*

*Carapace* – Anterior dorsal margin a broadly triangular, bluntly pointed, rostral plate extending just beyond base of eyestalks. Posterior dorsal margin concave, exposing eighth thoracic segment (Figure 2h).

*Antennal peduncle and scale* – Scale about 7.5 times as long as wide at its midlength, suture separating distal one fifth, setose along both margins, lacking lateral tooth. Third segment of peduncle about 0.8 times as long as second segment; entire peduncle shorter than scale (Figure 3h).

*Uropods* – Exopod about 1.8 times as long as telson and 1.4 times as long as endopod, outer margin slightly concave, setose along both margins. Inner margin of endopod bearing row of 14 to 21 spines of unequal size extending from area of statocyst distally along proximal two thirds; both inner and other margins setose (Figure 4h).

*Telson* – Broadly linguiform with rounded apex; proximal two thirds devoid of spines, distal one third of each margin bearing 11 to 15 spines of about equal size and spacing lateral to a longer pair of midapical spines (Figure 5h).

*Other characters* – All pleopods of males biramous, endopod of first pleopod rudimentary, exopod of fourth pleopod 6-segmented and bearing a long barbed seta off terminal segment. All pleopods of females reduced to uniramous plates.

*Remarks* – A certain confusion exists in the literature on the occurrence of several species of *Metamysidopsis* from northern Gulf waters. Tattersall (1951) reported *Metamysidopsis munda* (Zimmer, 1918) from Calcasieu Pass, Louisiana. Băcescu (1969) reviewed the genus *Metamysidopsis* and synonymized Tattersall's *M. munda* with *M. mexicana* Băcescu, 1969. An examination of Tattersall's material from Calcasieu Pass, Louisiana, revealed specimens to be *M. swifti* and not *M. munda* or *M. mexicana*. Specimens identified as *M. mexicana* from Mullet Key, off Tampa, Florida, obtained from the U.S. National Museum, were also examined and found to be *M. swifti*; however, the antennal scale and peduncle were of the size and proportions similar to *M. mexicana*. Of the hundreds of specimens examined from the northern Gulf, none have been identifiable to either *M. mexicana* or *M. munda*. We therefore believe that neither *M. mexicana* nor *M. munda* has been reported reliably from the coastal waters of the northern Gulf.

*Length* – Adult males to 4.8 mm and females to 5.5 mm.

*Ecology* – Upper mesohaline, abundant in surf zone.

### *BATHYMYSIS RENOCULATA* TATTERSALL, 1951

#### *Description*

*Carapace* – Anterior dorsal margin a well-developed triangular rostral plate, apex pointed and extending well between eyes. Posterior dorsal margin concave, exposing eighth and part of seventh thoracic segments (Figure 2i).

*Antennal peduncle and scale* – Scale about 7.5 times as long as wide at its midlength, with distal suture, setose along both margins, lacking lateral tooth. Third segment of peduncle about 0.6 times as long as second segment; entire peduncle slightly more than one half the length of scale (Figure 3i).

*Uropods* – Exopods about 1.6 times as long as telson and about 1.3 times as long as endopods, very slender in appearance, setose along both margins. Endopods about 1.2 times as long as telson, bearing a row of about 33 equally spaced spines that gradually increase in length from area of statocyst to apex, both inner and outer margins setose (Figure 4i).

*Telson* – About twice as long as maximum width, lateral margins armed with about 25 to 40 long spines, more concentrated along the distal margins; each apical lobe armed with 2 spines slightly longer than those along lateral margins. Terminal cleft deep, about one fifth of the total length of telson, bearing about 30 short spines proximally and 3 pairs of larger spines distally (Figure 5i).

*Other characters* – Pleopods of males biramous, endopod of first pleopod rudimentary, exopod of fourth pleopod 8-segmented and about twice as long as endopod, distal margin of sixth and seventh segments of exopod each bearing a long plumose seta, eighth segment reduced and bearing 1 long and 1 short simple seta.

*Length* – Adult males and females to 9.0 mm.

*Ecology* – Polyhaline, hypoplanktonic.

### *MYSIDOPSIS BIGELOWI* TATTERSALL, 1926

#### *Description*

*Carapace* – Anterior dorsal margin a short, bluntly pointed rostral plate partly covering and extending slightly beyond base of eyestalks. Posterior dorsal margin slightly concave, loose, exposing eighth and part of seventh thoracic segments (Figure 2j).

*Antennal peduncle and scale* – Scale about 6.5 times as long as wide at its midlength, bearing setae along both margins, without lateral tooth or distal suture. Third segment of peduncle about 0.6 times as long as second segment; entire peduncle about 0.6 times as long as scale (Figure 3j).

*Uropods* – Exopods about twice as long as telson and about 1.2 times as long as endopods, setose along both margins. A row of 4 or 5 graduated spines present along inner margin of endopod medial to statocyst, proximal spine being shortest and distal spine longest (Figure 4j).

*Telson* – Broadly linguiform, without terminal cleft or emargination, length about 1.6 times maximum width; lateral margins slightly concave, bearing 10 to 13 short, stout, evenly spaced spines; apex rounded, bearing 3 pairs of widely spaced spines, the inner 2 pairs subequal in length and much longer than outer pair (Figure 5j).

*Other characters* – Endopod of second thoracic limb greatly enlarged. Pleopods of males biramous, endopod of pleopod 1 rudimentary, exopod of pleopod 4 bearing a long barbed seta on the terminal seventh segment. All pleopods of females reduced to uniramous plates.

*Remarks* – *Mysidopsis bigelowi* is easily distinguished from the other species of *Mysidopsis* in the present key by the greatly enlarged endopod of the second thoracic limb.

*Length* – Adult males and females to 7.0 mm.

*Ecology* – Polyhaline, hypoplanktonic, abundant in offshore waters.

### *MYSIDOPSIS FURCA* BOWMAN, 1957

#### *Description*

*Carapace* – Anterior dorsal margin a bluntly triangular rostral plate extending only to base of eyestalks. Posterior dorsal margin loose, concave, exposing eighth and part of seventh thoracic segments (Figure 2k).

*Antennal peduncle and scale* – Scale about 4.7 times as long as wide at its midlength, bearing setae along both margins, without lateral tooth, faint suture present on distal tip. Third segment of peduncle about 0.6 times as long as second segment; entire peduncle about 0.6 times as long as scale (Figure 3k).

*Uropods* – Exopods about 1.2 times as long as endopods, slightly less than 1.5 times as long as telson in males, more than 1.5 times as long as telson in females. Endopods with

row of 30 to 40 strong spines of variable length along inner margin extending from statocyst to near distal tip. Endopods and exopods bearing setae along both margins (Figure 4k).

*Telson* – Showing sexual dimorphism. Female telson very distinctive, resembling a pitch fork; length about 1.2 times as long as maximum width; lateral margins concave, bearing 7 to 10 spines; apex armed with 2 pairs of long heavy spines, outer pair curved inward and inner pair almost straight (Figure 5l). Male telson about 1.4 times as long as maximum width; lateral margins less concave than in females and bearing 10 to 12 spines; apex with 2 pairs of straight spines, outer pair about one-half length of inner pair (Figure 5k). Telson with slight emargination between the inner pair of spines in both males and females.

*Other characters* – Pleopods of males biramous, endopod of pleopod 1 rudimentary; endopod and exopod of fourth pleopod of males subequal in length, exopod 7-segmented, bearing a long barbed seta on distal tip. All pleopods of females reduced to uniramous plates.

*Remarks* – *Mysidopsis furca* is easily distinguished from the other species of *Mysidopsis* in the present key by the armature and emargination of the distal end of the telson as well as by the large number and size of the spines on the endopods of the uropods. The female telson and uropods agree closely with the descriptions by Bowman (1957) but differ from those of Brattegard (1969), who apparently illustrated immature specimens.

*Length* – Adult males and females to 6.0 mm.

*Ecology* – Polyhaline, hypoplanktonic.

### *MYSIDOPSIS BAHIA* MOLENOCK, 1969

#### *Description*

*Carapace* – Anterior dorsal margin a broadly rounded rostral plate extending to base of eyestalks. Posterior dorsal margin loose, slightly concave, exposing eighth thoracic segment (Figure 2l).

*Antennal peduncle and scale* – Scale about 7.0 times as long as wide at its midlength, bearing setae along both margins, without distal suture or lateral tooth. Third segment of peduncle about 0.7 times as long as second segment; entire peduncle slightly less than one-half total length of scale (Figure 3l).

*Uropods* – Exopod about 1.8 times as long as telson and about 1.3 times as long as endopods, bearing setae along both margins. Endopod about 1.2 times as long as telson, bearing setae along each margin, with 2 or 3 (rarely 4) slender spines medial and slightly posterior to statocyst (Figure 4l).

*Telson* – Linguiform, without terminal cleft or emargination, length about 1.7 times maximum width; lateral margins slightly concave, bearing 10 to 21 spines; apex broadly rounded, bearing 4 to 6 pairs of closely set spines abruptly increasing in length from lateral-most pair to medial pair (Figure 5m).

*Other characters* – All pleopods of males biramous, endopod of pleopod 1 rudimentary, fourth pleopod bearing a long barbed seta on tip of 7-segmented exopod. All pleopods of females reduced to uniramous plates.

*Remarks* – Many specimens of *M. bahia* examined from the northern Gulf displayed variable concentrations of heavy black pigmentation along the entire ventral margin in addition to the normal ventral abdominal pigments characteristic of other species of *Mysidopsis*.

*Length* – Adult males to 7.0 mm and females to 8.0 mm.

*Ecology* – Estuarine, commonly occurring in salinities above 15.0 °/₀₀, rarely taken in salinitites as low as 2.0 °/₀₀, often collected with *M. almyra*.

### *MYSIDOPSIS ALMYRA* BOWMAN, 1964

#### *Description*

*Carapace* – Anterior dorsal margin a broadly rounded rostral plate, not produced between eyestalks. Posterior dorsal margin loose, concave, exposing eighth and part of seventh thoracic segments (Figure 2m).

*Antennal peduncle and scale* – Scale about 7.0 times as long as wide at its midlength, bearing setae along both margins, without distal suture or lateral tooth. Third segment of peduncle about 0.7 times as long as second segment; entire peduncle slightly less than one-half length of scale (Figure 3m).

*Uropods* – Exopods about 2.0 times as long as telson and 1.3 times as long as endopods, bearing setae along both margins. Endopods about 1.2 times as long as telson, bearing setae along both margins and 1 spine just posterior and medial to statocyst (Figure 4m).

*Telson* – Linguiform, without terminal cleft or emargination, length about 1.6 times maximum width; lateral margins slightly concave, bearing 15 to 24 spines of variable size, but generally increasing in length distally; apex rounded, bearing 6 to 8 pairs of spines gradually increasing in length from lateral-most pair to medial pair (Figure 5n).

*Other characters* – Pleopods of males biramous, endopod of pleopod 1 rudimentary, fourth pleopod bearing a long barbed seta on distal end of 7-segmented exopod. All pleopods of females reduced to uniramous plates.

*Remarks* – This species superficially resembles *M. bahia*, therefore careful determination of the spination of the inner ramous of the uropod is necessary.

*Length* – Adult males to 7.5 mm and females to 10.0 mm.

*Ecology* – Dominant mysid in northern Gulf estuaries, common in mesohaline to near fresh conditions, found over a salinity range of 0.0 to 32.0 °/₀₀, an important food item for local juvenile demersal fishes.

### *BRASILOMYSIS CASTROI* BĂCESCU, 1968

#### *Description*

*Carapace* – Anterior dorsal margin a large, triangular

bluntly pointed rostral plate extending well beyond eyestalks. Posterior dorsal margin concave, loose, exposing eighth and part of seventh thoracic segments (Figure 2n).

*Antennal peduncle and scale* – Scale very slender, about 15.0 times as long as wide at its midlength, suture separating distal one seventh, setose along both margins, lacking lateral tooth. Second segment of peduncle about 2.5 times as long as third segment; entire peduncle about 0.6 times as long as scale. Sympod with minute tooth on lateral margin (Figure 3n).

*Uropods* – Exopod about 1.25 times as long as telson and 1.2 times as long as endopods, outer margin concave, both margins setose. Endopod with large statocyst, setose along both margins, lacking spines along inner margin (Figure 4n).

*Telson* – Linguiform, very distinctive in appearance, without terminal notch; proximal one half of lateral margins armed with about 15 widely spaced spines becoming longer and more concentrated distally, distal one half armed with 40 to 60 (total both margins) closely set spatulate spines which are continuous around apex (Figure 5o).

*Other characters* – Eighth thoracic limb always directed backward, endopods well-developed with proximal two thirds of merus (longest segment) armed with 4 to 5 straight spines along outer margin and a row of 8 to 12 strong curved spines along inner, lower margin. First male pleopod uniramous, all others biramous, exopod of fourth pleopod with a long barbed seta extending from terminal segment. All pleopods of females reduced to uniramous plates. Entire body form very slender in appearance.

*Length* – Adult males and females to 8.0 mm.

*Ecology* – Upper mesohaline to polyhaline, hypoplanktonic.

### *HETEROMYSIS FORMOSA* S. I. SMITH, 1873

#### *Description*

*Carapace* – Anterior dorsal margin broadly triangular, a bluntly pointed rostral plate covering base of eyestalks. Posterior dorsal margin deeply concave, exposing eighth and part of seventh thoracic segments (Figure 2o).

*Antennal peduncle and scale* – Scale short, broadly rounded inner margin, about 2.6 times as long as wide at its midlength, setose along both margins, without suture or lateral tooth. Third segment of peduncle about 0.8 times as long as second segment; entire peduncle about equal in length to scale. Outer distal corner of sympod with a small tooth (Figure 3o).

*Uropods* – Exopods broadly rounded, slightly longer than endopods and telson, setose along both margins. Endopods about equal in length to telson, bearing a row of 16 to 19 spines of equal size and spacing along inner margins, both inner and outer margins setose (Figure 4o).

*Telson* – About 1.6 times as long as maximum width; lateral margins nearly straight, devoid of spines along proximal half, distal half bearing 10 to 18 spines of equal size and spacing; each apical lobe bearing 1 large spine. Terminal cleft deep and broad, containing a total of 16 to 30 laminae (Figure 5p).

*Other characters* – Endopod of third thoracic limb (males and females) with carpus and propodus fused to form a long undivided segment armed with 3 pairs of strong spines on the inner distal margin. Pleopods of both males and females rudimentary.

*Ecology* – Polyhaline, hypoplanktonic.

### *TAPHROMYSIS LOUISIANAE* BANNER, 1953

#### *Description*

*Carapace* – Rostral plate short and bluntly rounded, barely reaching base of eyestalks. Anterior margin of carapace with a small acute tooth just below level of eyestalk. Posterior dorsal margin slightly concave, loose, exposing eighth and part of seventh thoracic segments (Figure 2p).

*Antennal peduncle and scale* – Scale about 5.0 times as long as wide at its midlength, bearing setae along both margins, distal tip demarked by a faint suture, lacking lateral tooth. Third segment of peduncle about 0.7 times as long as second segment, distal margin reaching just beyond middle of scale (Figure 3p).

*Uropods* – Exopods about twice as long as telson, bearing setae along both margins. Endopods about 0.8 times as long as exopods, setose along both margins and bearing 1 long spine just posterior to statocyst along medial margin (Figure 4p).

*Telson* – Short, broad and distally emarginate; lateral margins slightly concave, bearing 10 to 12 spines along each side. Terminal emargination U-shaped, armed with 40 or more laminae along entire distal margin (Figure 5q).

*Other characters* – First and second pleopods of males rudimentary; exopod of fourth pleopod 6-segmented, distal end bearing a terminal and subterminal seta forming a "pincer-like" structure; terminal seta spinous, tip acute. All pleopods of females reduced to uniramous plates.

*Remarks* – The above diagnosis differs from the original description of *T. louisianae* by Banner (1953) who did not report the presence of the spine near the statocyst.

*Length* – Adult males and females to 9.0 mm.

*Ecology* – Estuarine, not collected in salinities above 2.0 °/oo, common in freshwater ditches.

### *TAPHROMYSIS BOWMANI* BĂCESCU, 1961

#### *Description*

*Carapace* – Rostral plate short and bluntly rounded, barely reaching base of eyestalks. Anterior margin of carapace devoid of spines. Posterior margin of carapace concave, loose, exposing seventh and eighth thoracic segments (Figure 2q).

*Antennal peduncle and scale* – Scale about 4.2 times as long as wide at its midlength, bearing setae along both margins, distal tip demarked by a faint suture, devoid of lateral tooth. Third segment of peduncle about 0.7 times as long as second segment; entire peduncle about two thirds of scale (Figure 3q).

*Uropods* – Exopods about 1.5 times as long as telson and slightly longer than endopods. Both endopods and exopods bearing setae along both margins. Endopods bearing 1 long spine located medial and posterior to statocyst (Figure 4q).

*Telson* – Short, broad and distally emarginate; lateral margins bearing 8 to 10 spines on each side, distal one half straight. Terminal emargination broadly V-shaped and armed with 30 or less laminae (spine-like projections) along entire distal margin (Figure 5r).

*Other characters* – Pleopods 1 and 2 of males rudimentary; exopod of fourth pleopod 6-segmented, distal end bearing a terminal and subterminal seta forming a "pincer-like" structure; terminal seta of outer ramous bifid at its tip as opposed to acute in *T. louisianae*. All pleopods of females reduced to uniramous plates.

*Remarks* – Many of the specimens from Mississippi show heavy pigmentation on the dorsal surface. Specimens of *T. bowmani* obtained from Destin, Florida, agree in all details with the original description by Băcescu (1961) and Brattegard (1970); however, material taken east of Mobile Bay showed considerable variation. The telson of *T. bowmani* from St. Louis Bay, Mississippi, (Figure 5s) closely resembles that of *T. louisianae* in having slightly concave lateral margins which bear 10 or more spines and a U-shaped emargination containing 30 to 36 laminae. The size and proportions of the antennal scale and peduncle also more closely resemble *T. louisianae*. These specimens lack the distinctive spine on the anterior carapace of *T. louisianae* and the mouthparts, thoracic limbs and male fourth pleopod are all clearly closer to *T. bowmani*. The spine on the inner margin of the endopod of the uropod is of a size and position consistent with *T. bowmani* (Figure 4r). Specimens of both *T. louisianae* and this "intermediate" form of *T. bowmani* have occurred simultaneously in samples from Davis Bayou and St. Louis Bay, Mississippi, and Lake Pontchartrain, Louisiana. The senior author is currently investigating the possibility that this "intermediate" form represents a hybrid of the two species, or yet an undescribed third species of *Taphromysis*.

*Length* – Adult males to 8.5 mm and females to 9.0 mm.

*Ecology* – Estuarine, found over a much wider range of salinity than the closely related species, *T. louisianae*.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Thomas E. Bowman of the National Museum of Natural History for his critical review of the manuscript, confirmation of identification of selected species and the loan of pertinent specimens from the Museum. Thanks are also due to Don Watson who inked all line drawings and to Adrian Lawler for his helpful criticisms and suggestions. For his support and encouragement we are grateful to Thomas McIlwain.

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


## Records and Range Extensions of Mycidacea from Coastal and Shelf Waters of the Eastern Gulf of Mexico


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DOI: 10.18785/grr.0603.04





Recommended Citation

Stuck, K. C., H. M. Perry and R. W. Heard. 1979. Records and Range Extensions of Mycidacea from Coastal and Shelf Waters of the Eastern Gulf of Mexico. Gulf Research Reports 6 (3): 239-248.
Retrieved from http://aquila.usm.edu/gcr/vol6/iss3/4

*Gulf Research Reports*, Vol. 6, No. 3, 239–248, 1979.

# RECORDS AND RANGE EXTENSIONS OF MYSIDACEA FROM COASTAL AND SHELF WATERS OF THE EASTERN GULF OF MEXICO

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*ABSTRACT* Records of seventeen species of Mysidacea from the Gulf of Mexico are presented. *Bowmaniella portoricensis, Pseudomma* sp., *Sirlella thompsonii* and *Bathymysis renoculata* are recorded from the Gulf for the first time. Range extensions within the Gulf are established for *Anchialina typica* and *Mysidopsis furca*. Records of *Brasilomysis castroi* and *Mysidopsis almyra* from the Atlantic coast of the United States are reported.

## INTRODUCTION

The offshore benthic and planktonic mysidacean fauna of the Gulf of Mexico are poorly known; however, the shallow-water species have been investigated by several authors. Brattegard (1969, 1970) reported eight species from coastal waters off southern Florida and presented their taxonomic characters. Farrell (1979) provided a key to 24 nearshore species from Florida but did not include data on collection sites. The Mysidacea of the western Gulf of Mexico have been studied by Price, who identified seven species from Galveston Bay, Texas (1976), and four species from Mexico (1975, 1978). The taxonomic works of Banner (1953), Clarke (1956), Băcescu (1961, 1969), Bowman (1964) and Molenock (1969) have also added to the knowledge of the group in the Gulf of Mexico. Ecological studies and baseline inventories in northern Gulf estuaries have contributed data on a limited number of species (cited in text).

Records of some Mysidacea from the Gulf of Mexico appear to be in error, due in part to confusion in the literature (Stuck et al. 1979). In addition to establishing new records and range extensions for Gulf mysids, data are presented here to clarify the known distribution of several shallow-water species.

## MATERIALS AND METHODS

This report is based on a collection of mysid shrimps of the family Mysidae from the continental shelf waters off Mississippi, Alabama, and Florida, and supplemented with material from shallow, estuarine waters in the northeastern Gulf of Mexico. Specimens were provided to the authors from the following sources:

1. National Marine Fisheries Service under Public Law 88–309, Project 2–42–R.
2. National Marine Fisheries Service under Public Law 88–309, Project 2–215–R.
3. Dames and Moore under Contract N. AA550–CT7–34 from the Bureau of Land Management.
4. Steve Heath, Alabama Marine Resources Laboratory; specimens from Dauphin Island and Gulf Shores, Alabama.
5. Shiao Wang, Gulf Coast Research Laboratory; specimens from continental shelf waters off Main Pass, Mississippi River.
6. Steve Manning, Gulf Coast Research Laboratory; specimens from Gulf Breeze, Florida.
7. Thomas E. Bowman, United States National Museum; specimens from Mullet Key, Florida, and Calcasieu Pass, Louisiana.
8. The personal collections of Kenneth C. Stuck (KCS) and Richard W. Heard (RWH).

Records of occurrence follow the style of Brattegard (1969, 1970). Plankton stations are designated as either day (D) or night (N) and are followed by the depth of tow (S–surface, M–midwater, B–bottom). Selected synonymies of interest to regional investigators are provided for each species when applicable. The study area, divided into four subareas based on geographic location, and collecting sites are shown in Figures 1 through 5.

Specimens were taken with a variety of gear types and these are included with station location and bottom type in the collecting sites listing. Sediment analysis was not available for many locations.

A representative collection of the mysids reported herein has been deposited in the museum at the Gulf Coast Research Laboratory, Ocean Springs, Mississippi.

## COLLECTING SITES

1. Timbalier Bay, Louisiana; mud; Renfro beam trawl.
2. Terrebonne Parish, Louisiana; Gulf surf, sand; Renfro beam trawl.
3. Forty-two miles east of Main Pass, Mississippi River, 88°30′ N, 29°25′W; plankton net.
4. Mouth of Bayou St. John, Orleans Parish, Louisiana; sand; Renfro beam trawl.
5. South shore of Lake Pontchartrain, Louisiana; sand, grass bed; Renfro beam trawl.

Manuscript received September 7, 1979; accepted October 3, 1979.

6. North shore of Lake Pontchartrain, Louisiana; sand, grass bed; Renfro beam trawl.

7. Cedar Point, St. Louis Bay, Mississippi; silty sand; Renfro beam trawl.

8. Henderson Point, Pass Christian, Mississippi; sand; Renfro beam trawl.

9. Gulfport Beach, Gulfport, Mississippi; sand; Renfro beam trawl.

10. East end of Deer Island, Mississippi; mud; Renfro beam trawl.

11. Fort Point, Biloxi Bay, Mississippi; sand, grass bed; Renfro beam trawl.

12. Davis Bayou, Mississippi; mud; Renfro beam trawl.

13. Belle Fontaine Beach, Mississippi; silty sand; Renfro beam trawl.

14. Cat Island Pass, Mississippi; Clarke-Bumpus plankton sampler.

15. Ship Island Pass, Mississippi; Clarke-Bumpus plankton sampler.

16. Ship Island; Gulf surf, sand; Renfro beam trawl.

17. Continental shelf, north central Gulf of Mexico, 30°02′30″ N, 88°40′15″ W; plankton net.

18. Continental shelf, north central Gulf of Mexico, 29°42′00″ N, 88°27′30″ W; plankton net.

19. Continental shelf, north central Gulf of Mexico, 29°24′15″ N, 88°17′00″ W; plankton net.

20. Continental shelf, north central Gulf of Mexico, 20°19′00″ N, 88°14′00″ W; plankton net.

21. Continental shelf, north central Gulf of Mexico, 29°17′15″ N, 88°12′05″ W; plankton net.

22. Dog Keys Pass, Mississippi; Clarke-Bumpus plankton sampler.

23. Chimney Lagoon, Horn Island, Mississippi; silty sand; Renfro beam trawl.

24. Middle Ground, Mississippi Sound; sand, grass bed; Refro beam trawl.

25. Horn Island Pass, Mississippi; Clarke-Bumpus plankton sampler.

26. Dauphin Island, Alabama; gear type unknown.

27. Gulf Shores, Alabama; gear type unknown.

28. Gulf Breeze, Florida; sand; Renfro beam trawl.

29. Brackish water pond, Destin, Florida; sand; fine-mesh dip net.

30. Continental shelf, north central Gulf of Mexico, 29°43′29″ N, 87°54′30″ W; box core.

31. Continental shelf, NE Gulf of Mexico, 29°47′59″ N, 86°09′29″ W; box core.

32. Continental shelf, NE Gulf of Mexico, 28°23′59″ N, 85°15′03″ W; box core.

33. Continental shelf, NE Gulf of Mexico, 27°57′00″ N, 84°47′59″ W; box core.

34. Continental shelf, NE Gulf of Mexico, 29°47′00″ N, 84°05′00″ W, box core.

35. Continental shelf, NE Gulf of Mexico, 29°05′01″ N, 83°45′01″ W; box core.

36. Continental shelf, NE Gulf of Mexico, 28°30′00″ N, 83°29′58″ W; box core.

37. Continental shelf, NE Gulf of Mexico, 27°57′00″ N, 83°09′00″ W; box core.

38. Continental shelf, NE Gulf of Mexico, 27°56′01″ N, 83°27′30″ W; box core.

39. Continental shelf, NE Gulf of Mexico, 27°52′31″ N, 83°33′59″ W; box core.

40. Continental shelf, NE Gulf of Mexico, 27°57′29″ N, 83°42′29″ W; box core.

41. Continental shelf, NE Gulf of Mexico, 27°56′30″ N, 83°53′00″ W; box core.

42. Continental shelf, NE Gulf of Mexico, 27°37.2′ N, 83°53.5′ W; box core.

43. Continental shelf, NE Gulf of Mexico, 27°24.2′ N, 84°07.3′ W; box core.

44. Continental shelf, SE Gulf of Mexico, 27°03′26″ N, 83°01′09″ W; box core.

45. Continental shelf, SE Gulf of Mexico, 26°25′00″ N, 82°15′09″ W; box core.

46. Continental shelf, SE Gulf of Mexico, 26°25′00″ N, 82°58′00″ W; box core.

47. Continental shelf, SE Gulf of Mexico, 26°25′00″ N, 83°23′01″ W; box core.

48. Continental shelf, SE Gulf of Mexico, 25°40.0′ N, 82°20.0′ W; box core.

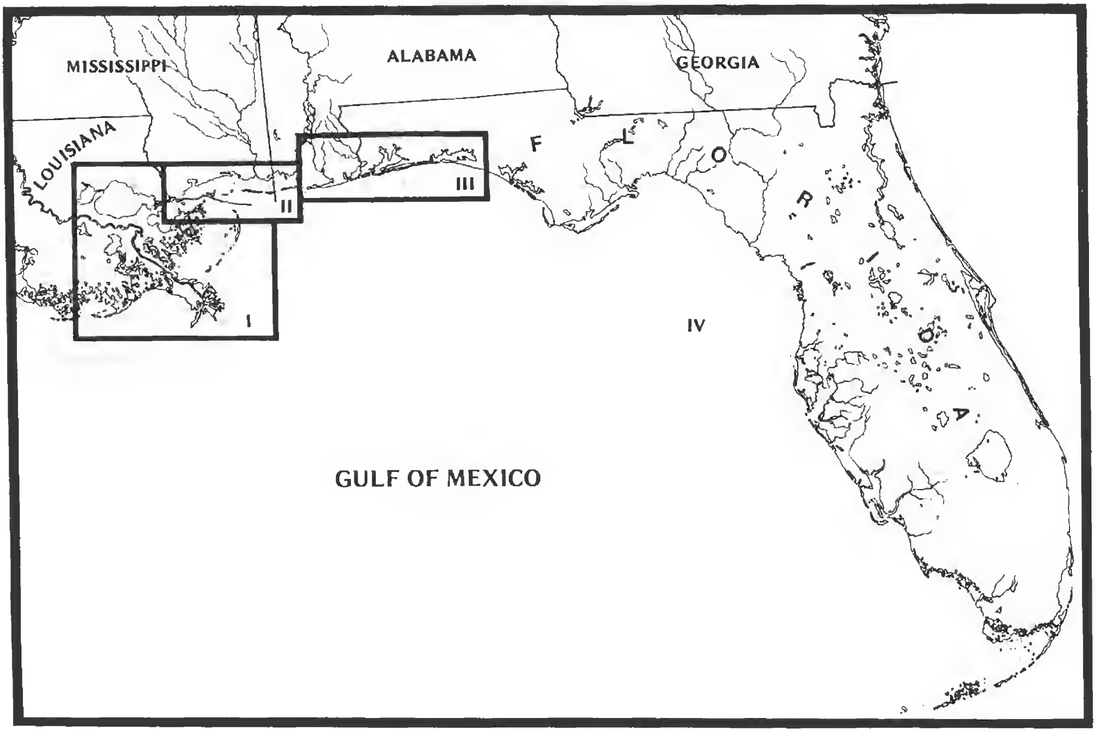


Figure 1. Study area showing locations of subareas I through IV.

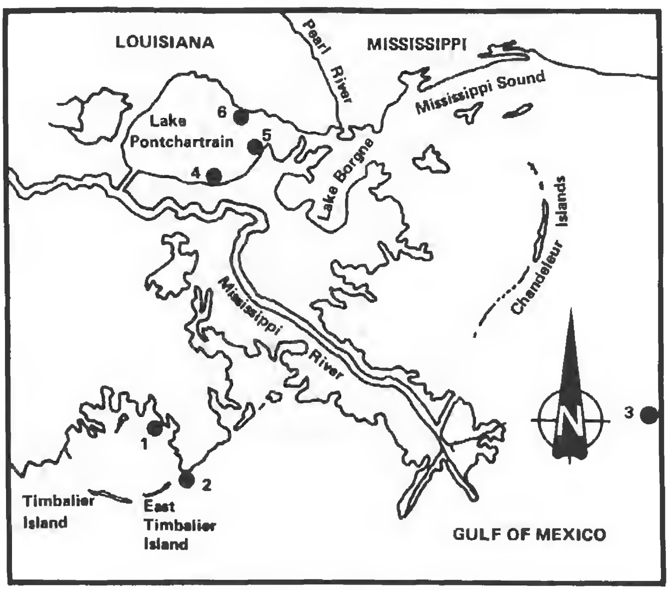


Figure 2. Location of stations in subarea I.

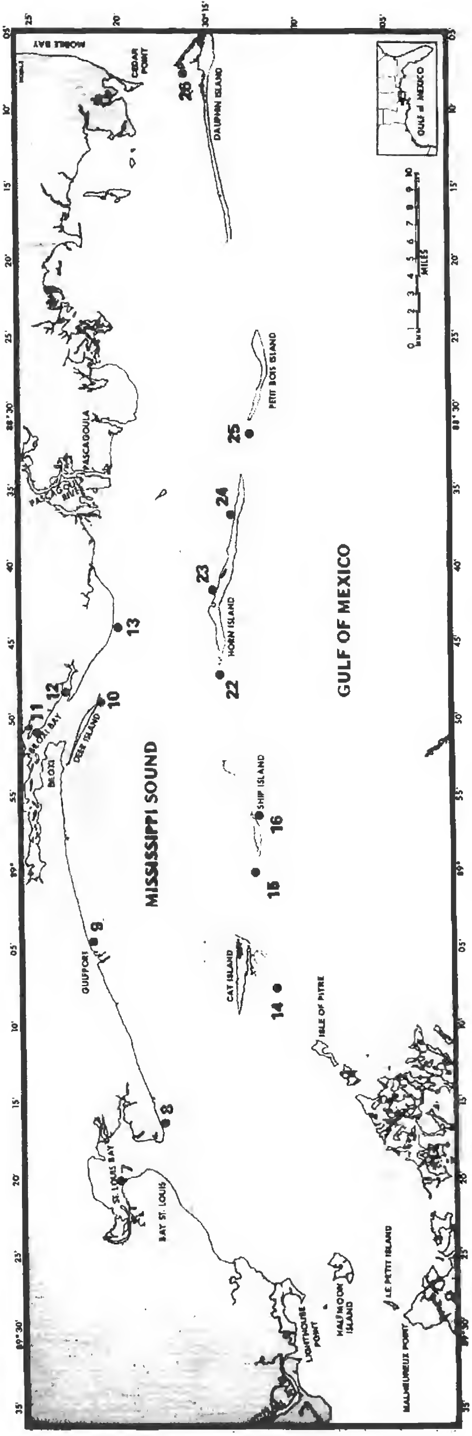


Figure 3. Location of stations in subarea II.

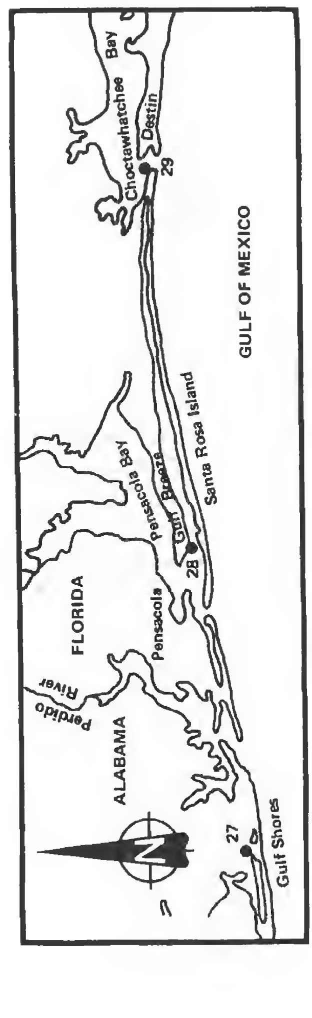


Figure 4. Location of stations in subarea III.

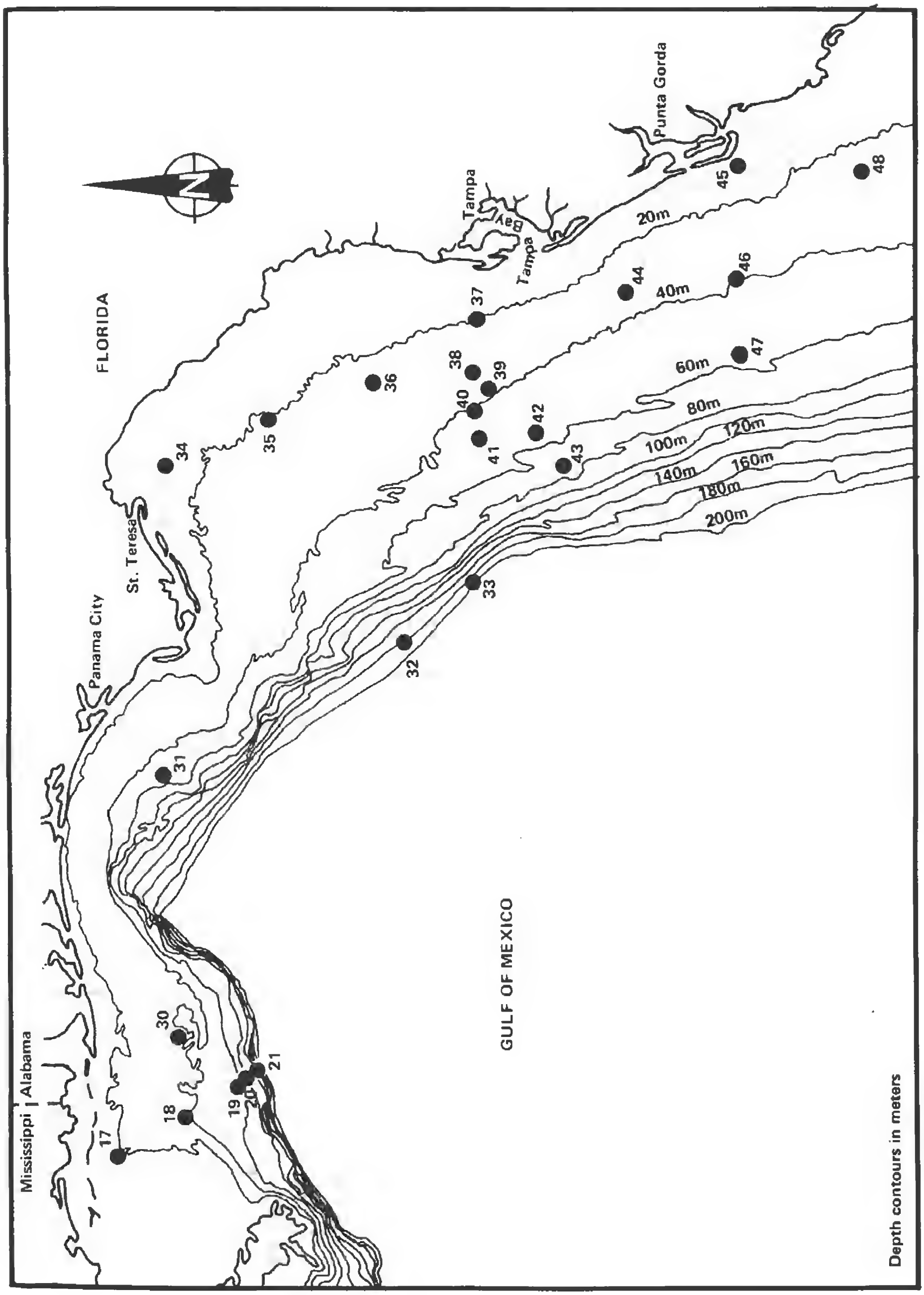


Figure 5. Location of stations in subarea IV.

## SPECIES ACCOUNT

### *Anchialina typica* (Krøyer)

*Anchialus typicus* Krøyer, 1861, p. 53, pl. 2, fig. 7a–l
*Anchialina typica:* Hansen, 1910, p. 52, pl. 7, fig. 2a–k
*Anchialina typica:* Ii, 1964, p. 188, figs. 48–49
*Anchialina typica:* Brattegard, 1970, p. 24, fig. 6
*Anchialina typica:* Stuck, Perry and Heard, 1979, p. 227, figs. 2a, 3a, 4a, 5a

*Occurrence* – Station 19NM(males–4, females–1, ovigerous females–0, juveniles–0), 20NM(1–3–1–0), 21NM (0–0–1–0), 31(1–0–0–0), 34(0–1–0–0), 35(1–0–0–0), 37(1–0–0–0), 42(0–1–0–0), 45(0–1–0–0), 48(0–0–0–1).

*Gulf of Mexico Records* – Hopkins (1966).

*Distribution* – Widely distributed in the tropical and subtropical regions of the Atlantic and Pacific oceans (Ii 1964). Reported from waters off Nova Scotia (Nouvel 1943), the continental shelf off South Carolina (Wigley and Burns 1971), Biscayne Bay, Florida (Brattegard 1970). St. Andrew Bay, Florida (Hopkins 1966), and the continental shelf waters off Mississippi (present study).

### *Bowmaniella portoricensis* Băcescu

*Bowmaniella portoricensis* Băcescu, 1968, p. 357, figs. 1a–n, 2a–e, 3a–b
*Bowmaniella portoricensis:* Stuck, Perry and Heard, 1979, p. 227, figs. 2b, 3b, 4b, 5b

*Occurrence* – Station 19DB(males–1, females–21, ovigerous females–0, juveniles–0), 20NM(0–0–0–2), 30(0–1–0–0), 35(0–1–0–0), 37(0–1–0–0), 38(1–4–0–1), 39(1–0–0–0), 40(1–1–0–0), 46(0–1–0–0), 47(0–4–0–0), 48(0–1–0–0).

*Gulf of Mexico Records* – Previously unreported.

*Distribution* – Cape Hatteras, North Carolina, to Fort Pierce, Florida (Wigley and Burns 1971), and continental shelf waters off Mississippi (present study).

### *Bowmaniella floridana* Holmquist

*Gastrosaccus dissimilis* Tattersall, 1951 (in part), p. 97, fig. 29
*Bowmaniella dissimilis:* Brattegard, 1970, p. 11, fig. 2
*Bowmaniella floridana* Holmquist, 1975, p. 68
*Bowmaniella floridana*: Stuck, Perry and Heard, 1979, p. 232, figs. 2c, 3c, 4d, 5c

*Occurrence* – Mature males only, station 12(4), 13(6), 24(4).

*Gulf of Mexico Records* – Tattersall (1951), Hopkins (1966), Băcescu (1968a), Brattegard (1970), Solomon (1970), Mackin (1971), Odum and Heald (1972), Williams (1972), Christmas and Langley (1973), Livingston et al. (1977), Cooley (1978).

*Distribution* – In question.

*Remarks* – The taxonomic status of *B. floridana* is currently being reviewed by Thomas E. Bowman of the United States National Museum. Stuck et al. (1979) have discussed the taxonomic problems associated with *B. floridana, B. dissimilis* and *B. brasiliensis.*

### *Bowmaniella brasiliensis* Băcescu

*Bowmaniella brasiliensis* Băcescu, 1968a, p. 363, figs. 5a–d, 6
*Bowmaniella brasiliensis*: Stuck, Perry and Heard, 1979, p. 233, figs. 2d, 3d, 4c, 5d

*Occurrence* – Mature males only, station 12(4), 13(6), 24(3), 26(2).

*Gulf of Mexico Records* – Conte and Parker (1971), Mackin (1971), Price (1976, 1978).

*Distribution* – Georgia (Brattegard 1974) to Brazil (Băcescu 1968a).

*Remarks* – See Stuck et al. (1979).

### *Pseudomma* sp.

*Occurrence* – Station 20NM(females–2, juveniles–2).

*Gulf of Mexico Records* – Genus previously unreported.

*Remarks* – This appears to be an undescribed species of *Pseudomma;* however, description awaits the collection of male specimens.

### *Siriella thompsonii* (H. Milne-Edwards)

*Cynthia thompsonii* H. Milne-Edwards, 1837, p. 462
*Siriella thompsoni*: Sars, 1885, p. 205, pl. 36, figs. 1–24
*Siriella thompsoni*: Ii, 1964, p. 62, figs. 14a–h, 15a–n
*Siriella thompsonii*: Stuck, Perry and Heard, 1979, p. 234, figs. 2f, 3f, 4f, 5f

*Occurrence* – Station 17DM(males–1, females–11, ovigerous females–2, juveniles–0), 17NM(6–28–0–3), 19DS (2–7–0–1), 19DB(2–0–1–0), 20NS(13–36–0–0), 21NS (2–4–1–0).

*Gulf of Mexico Records* – Previously unreported.

*Distribution* – Oceanic with wide distribution in the tropical and temperate waters of the world (Ii 1964). Reported from the Straits of Florida (Tattersall 1926), and the continental shelf waters off Mississippi (present study).

### *Promysis atlantica* W. M. Tattersall

*Promysis atlantica* W. M. Tattersall, 1923, p. 286, pl. 1, figs. 5–6
*Promysis atlantica*: Tattersall, 1951, p. 245, fig. 56
*Promysis atlantica*: Clarke, 1956, p. 1, figs. 1–6
*Promysis atlantica*: Stuck, Perry and Heard, 1979, p. 234, figs. 2g, 3g, 4g, 5g

*Occurrence* – Station 3DS(males–2, females–7, ovigerous females–0, juveniles–1), 15DB(0–4–0–1), 17NM (2–14–2–6), 18NM(0–2–2–0), 18NS(2–0–0–0), 18NB (0–1–0–0), 19DM(0–3–0–0), 19NS(0–1–0–1), 20NS (2–4–0–0), 21DB(6–9–1–0), 25DB(3–3–0–9).

*Gulf of Mexico Records* – Clarke (1956), Hopkins (1966), Price (1976).

*Distribution* – Brazil north throughout the Caribbean Sea, Gulf of Mexico and Atlantic coast of North America to just north of Cape Hatteras, North Carolina (Brattegard 1973).

### *Metamysidopsis swifti* Băcescu

*Metamysidopsis munda*: Tattersall, 1951 (in part), p. 147
*Metamysidopsis munda*: Hopkins, 1966, p. 47
*Metamysidopsis swifti* Băcescu, 1969, p. 350, fig. 1
*Metamysidopsis swifti*: Brattegard, 1970, p. 30, fig. 8
*Metamysidopsis swifti*: Stuck, Perry and Heard, 1979, p. 234, figs. 2h, 3h, 4h, 5h

*Occurrence* – Station 2(males–0, females–0, ovigerous females–2, juveniles–0), 13(0–4–0–0), 16(23–15–10–0), 26(0–1–0–0).

*Gulf of Mexico Records* – Băcescu (1969), Brattegard (1970), Price (1975, 1976).

*Distribution* – Mullet Key, Florida to Caribbean coast of Colombia (Brattegard 1973).

*Remarks* – *Metamysidopsis munda* was reported from Calcasieu Pass, Louisiana, by Tattersall (1951); however, an examination of these specimens revealed them to be *M. swifti*. Specimens identified as *M. mexicana* from Mullet Key, off Tampa, Florida, were provided to the authors by Thomas E. Bowman of the United States National Museum. These specimens were also found to be *M. swifti*, thus adding the eastern Gulf of Mexico to its known range.

### *Bathymysis renoculata* W. M. Tattersall

*Bathymysis renoculata* W. M. Tattersall, 1951, p. 153, figs. 57–58
*Bathymysis renoculata*: Stuck, Perry and Heard, 1979, p. 235, figs. 2i, 3i, 4i, 5i

*Occurrence* – Station 18NM(males–0, females–1, ovigerous females–0, juveniles–0), 20NM(1–0–0–1), 21NB (0–0–0–2), 32(0–1–0–0).

*Gulf of Mexico Records* – Previously unreported.

*Distribution* – Atlantic coast of the United States from New England to the southern tip of Florida (Tattersall 1951) and the north central Gulf of Mexico (present study).

*Remarks* – This species was previously known only from the deeper waters of the western Atlantic Ocean at depths from 220 to 483 meters. It was identified in the present study from continental shelf waters off western Florida at depths of 180 meters. The records from the shelf waters off Mississippi were at much shallower depths, ranging from 37 to 91 meters.

### *Mysidopsis bigelowi* W. M. Tattersall

*Mysidopsis bigelowi* W. M. Tattersall, 1926, p. 10, pl. 1, figs. 1–8
*Mysidopsis bigelowi*: Tattersall, 1951, p. 139, fig. 50
*Mysidopsis bigelowi*: Brattegard, 1969, p. 53, fig. 15
*Mysidopsis bigelowi*: Stuck, Perry and Heard, 1979, p. 235, figs. 2j, 3j, 4j, 5j

*Occurrence* – Station 14DB(males–0, females–1, ovigerous females–0, juveniles–8), 17NS(6–11–1–0), 17NM (7–7–3–0), 17NB(5–8–7–1), 18NS(4–3–0–5), 18NM (8–6–1–0), 19NB(0–3–2–0), 20NS(1–0–0–1), 20NM (4–7–0–0), 20DM(1–3–0–0), 21DB(0–1–0–0), 22DB (3–1–1–1), 25DB(7–2–2–12).

*Gulf of Mexico Records* – Tattersall (1951), Clarke (1956), Brattegard (1969), Solomon (1970), Mackin (1971), Price (1976), Livingston et al. (1977), Sheridan (1978).

*Distribution* – Aransas Bay, Texas (Solomon 1970), to Georges Bank (Wigley and Burns 1971).

### *Mysidopsis furca* Bowman

*Mysidopsis furca* Bowman, 1957, p. 1, figs. 1–2
*Mysidopsis furca*: Brattegard, 1969, p. 47, fig. 13
*Mysidopsis furca*: Stuck, Perry and Heard, 1979, p. 235, figs. 2k, 3k, 4k, 5k–l

*Occurrence* – Station 17NM(males–0, females–1, ovigerous females–1, juveniles–0), 18NM(0–3–0–0), 18NB (1–1–1–0), 34(1–2–0–0), 44(0–1–0–0), 45(2–0–0–0).

*Gulf of Mexico Records* – Brattegard (1969).

*Distribution* – North Inlet, South Carolina (Bowman 1957), to Pigeon Key, Florida (Brattegard 1969), and continental shelf waters off Mississippi (present study).

### *Mysidopsis bahia* Molenock

*Mysidopsis bahia* Molenock, 1969, p. 113, figs. 1–18
*Mysidopsis bahia*: Brattegard, 1970, p. 28, fig. 7
*Mysidopsis bahia*: Stuck, Perry and Heard, 1979, p. 236, figs. 2l, 3l, 4l, 5m

*Occurrence* – Station 1(males–1, females–0, ovigerous females–0, juveniles–0), 2(0–1–1–0), 6(0–1–0–0), 7(0–1–0–1), 10(1–1–2–0), 12(0–0–1–0), 23(6–6–9–0), 24(0–2–12–0), 27(8–6–7–1).

*Gulf of Mexico Records* – Molenock (1969), Brattegard (1970), Conte and Parker (1971), Mackin (1971), Odum and Heald (1972), Price (1976, 1978), Livingston et al. (1977), Sheridan (1978, 1979).

*Distribution* – Laguna de Tamiahua, Mexico (Price 1978), to Buttonwood Channel, Cape Sable, Florida (Brattegard 1970).

### *Mysidopsis almyra* Bowman

*Mysidopsis almyra* Bowman, 1964, p. 15, figs. 1–24
*Mysidopsis almyra*: Brattegard, 1969, p. 50, fig. 14
*Mysidopsis almyra*: Stuck, Perry and Heard, 1979, p. 236, figs. 2m, 3m, 4m, 5n

*Occurrence* – Station 1(males–14, females–13, ovigerous females–9, juveniles–10), 2(4–6–0–0), 4(13–12–1–7), 5(90–22–41–2), 6(28–25–22–1), 7(7–7–19–0),

8(2–11–11–2), 9(0–3–14–0), 10(15–5–9–0), 11(32–37–24–0), 12(24–25–69–0), 13(51–45–49–0), 15DB (1–1–0–4), 23(1–2–0–0), 24(7–3–4–0), 26(0–1–0–0), 27(10–5–3–2).

*Gulf of Mexico Records* – Bowman (1964), Hopkins (1966), Brattegard (1969), Conte and Parker (1971), Mackin (1971), Kalke (1972), Schmidt (1972), Odum and Heald (1972), Williams (1972), Christmas and Langley (1973), Subrahmanyam et al. (1976), Price (1976, 1978), Adkins and Bowman (1976), Tarver and Savoie (1976), Livingston et al. (1977), Desselle et al. (1978), Gillespie (1978), Cooley (1978), Sheridan (1978).

*Distribution* – Laguna de Tamiahua, Mexico (Price 1978), to St. Johns River, Florida (Price and Vodopich 1979), and Ormond Beach, Florida (personal collection of RWH).

### *Brasilomysis castroi* Băcescu

*Brasilomysis castroi* Băcescu, 1968b, p. 81, figs. 3–4
*Brasilomysis castroi*: Brattegard, 1969, p. 61, fig. 18
*Brasilomysis castroi*: Stuck, Perry and Heard, 1979, p. 236, figs. 2n, 3n, 4n, 5o

*Occurrence* – Station 15DB(males–0, females–0, ovigerous females–0, juveniles–1), 17NM(1–0–0–0), 18NS (1–1–0–0), 18NM(0–2–0–0), 22DB(0–1–0–1), 25DB (0–2–0–2).

*Gulf of Mexico Records* – Brattegard (1969), Conte and Parker (1971), Mackin (1971), Price (1976).

*Distribution* – Brazil (Băcescu 1968b) to coast of Georgia (Brattegard 1974), and St. Catherine's Sound, Georgia (personal collection of RWH).

### *Heteromysis formosa* S. I. Smith

*Heteromysis formosa* S. I. Smith, 1873, p. 553
*Heteromysis formosa*: Tattersall, 1951, p. 235, figs. 100, 101
*Heteromysis formosa*: Brattegard, 1969, p. 92, fig. 29
*Heteromysis formosa*: Stuck, Perry and Heard, 1979, p. 237, figs. 2o, 3o, 4o, 5p

*Occurrence* – Station 41(1 female).

*Gulf of Mexico Records* – Tattersall (1951).

*Distribution* – Western Atlantic from New England to the eastern Gulf of Mexico; eastern Atlantic Ocean, Norway, British Isles, France; Mediterranean off Monaco (Brattegard 1969).

*Remarks* – One of the authors (KCS) examined a 12.0-mm specimen (female) from continental shelf waters east of the mouth of Main Pass, Mississippi River.

### *Taphromysis louisianae* Banner

*Taphromysis louisianae* Banner, 1953, p. 3, figs. 1–2
*Taphromysis louisianae*: Stuck, Perry and Heard, 1979, p. 237, figs. 2p, 3p, 4p, 5q

*Occurrence* – Station 7(males–4, females–2, ovigerous females–0, juveniles–0).

*Gulf of Mexico Records* – Banner (1953), Conte and Parker (1971), Mackin (1971), Conte (1972), Kalke (1972), Cali (1972), Harrel et al. (1976), Livingston et al. (1977).

*Distribution* – Lavaca River, Texas (Mackin 1971), to Apalachicola Bay, Florida (Livingston et al. 1977).

### *Taphromysis bowmani* Băcescu

*Taphromysis bowmani* Băcescu, 1961, p. 517, figs. 1–2
*Taphromysis bowmani*: Brattegard, 1969, p. 89, fig. 28
*Taphromysis bowmani*: Stuck, Perry and Heard, 1979, p. 237, figs. 2q, 3q, 4q–r, 5r–s

*Occurrence* – Station 6(males–1, females–6, ovigerous females–0, juveniles–0), 7(1–1–0–15), 28(3–7–4–0), 29(3–2–0–0).

*Gulf of Mexico Records* – Hopkins (1966), Brattegard (1969), Odum and Heald (1972), Subrahmanyam et al. (1976), Beck (1977), Livingston et al. (1977), Bowman (1977), Cooley (1978), Sheridan (1978, 1979), Compton and Price (1979).

*Distribution* – Upper Laguna Madre (Compton and Price 1979), to Biscayne Bay, Florida (Băcescu 1961).

## ACKNOWLEDGMENTS

The authors thank Thomas E. Bowman of the United States National Museum for confirming the identification of critical material. We acknowledge Don Watson and Beryl Heard for their assistance in the preparation of illustrations. Appreciation is extended to A. G. Fish of the University of Southern Mississippi for providing the incentive to undertake this study.

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Gulf Research Reports

Volume 6 | Issue 3

January 1979

# Studies of the Southern Oyster Borer, *Thais haemastoma*

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DOI: 10.18785/grr.0603.05

*Gulf Research Reports*, Vol. 6, No. 3, 249–260, 1979.

# STUDIES OF THE SOUTHERN OYSTER BORER, *THAIS HAEMASTOMA*

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*ABSTRACT* Original work was carried on at the U.S. Bureau of Fisheries Laboratory on Apalachicola Bay from August 1935 to April 1936. Since then observations have been made in Texas, Louisiana and Mississippi. Five papers on specific aspects of the biology of the animal have been written since on this and other predatory gastropods. Here all commentaries are drawn together and unpublished matter is presented.

The name *Thais haemastoma* is used because separations based upon the rugosity of the shells do not hold up. Perfectly smooth and very rugose specimens are found in the same bays, with various shell characteristics being related to various oyster reefs on which they grow.

Radular movement is by the band-over-pulley method suggested by Husley (1853), Herrick (1906) Gunter (1936) and Carriker (1943). Evidence is presented showing that *Thais* can kill oysters without mechanical injury, presumbly by some paralytic material. About one-third of the oysters are opened by large *Thais* without any boring whatsoever. Smaller *Thais* are more prone to bore complete holes into the shell cavity of the prey. In Apalachicola Bay large *Thais* may eat one oyster about every 8 days and it was calculated that on St. Vincent's Bar 24 million adult oysters could be killed in a year.

The resting gonads consist of a thin layer of tissue on the body over the liver and they are lavender-grey in the males and yellowish-orange in the females. They begin to thicken in January and the color intensifies. Egg laying takes place from April to July on the Gulf coast. No young or small *Thais* were seen in Apalachicola Bay probably because of heavy fresh-water drainage in the springs of 1934 and 1935. Several hundred *Thais* were measured and each month the length frequency mode was at 80.0 mm. The largest known specimen of *Thais*, a Louisiana specimen, was 103 mm long.

A heavy kill of *Thais* took place in the spring of 1935 and no adults survived in Apalachicola Bay except on Hiles' Bar near Indian Pass, which is close to the ocean. The *Thais* seemed to perish when salinity dropped to 9‰ and stayed that way for several weeks. Both oysters and mussels survived at salinities lower than *Thais* could withstand.

*Thais* shells are extremely hard and are difficult to break with a hammer. Nevertheless, they are cracked by stone crabs. They are also invaded by commensals such as the boring clam *Diplothyra smithii*, the annelid worm *Polydora websteri*, and the boring sponge *Cliona*.

In Louisiana a so-called conch line was established by St. Amant (1938) when it was found that adult conchs did not get much beyond the area in Barataria Bay where the salinity fell to around 20‰. This was confirmed later by J. G. Mackin and Gunter at about 18‰, but has not been published. It has also been found that baby conchs are found landward of this line. It was found by experiments that conchs were generally killed by water registering 9‰ salinity and, additionally, that snails taken from low-salinity water survived transfer to still lower salinities or lived longer even in lethally low salinities than those coming from higher salinities.

Attempts to trap conchs on oyster beds were unsuccessful because no baits more attractive than the surrounding oysters and mussels could be found. The conchs' activity stopped at temperatures of 10°C and below.

## PROLOGUE

Generally the human equation is not mentioned in scientific papers, although authors sometimes speak sharply about the data or presentation of other writers in the same field. However, it will clarify things to explain why the work described herein was begun 45 years ago and is slow in coming to an end. In barest terms, it was started under Dr. Paul S. Galtsoff in Washington and his resident assistant at the Indian Pass Laboratory, who was not noted for productivity. Furthermore, neither Dr. Galtsoff nor the writer was widely known for amiability and forbearance in those days. The upshot was that in less than eight months I turned in a report and left the employ of the U.S. Bureau of Fisheries permanently in 1936. Publication as a bureau paper was not approved. I kept the manuscript with the hope of adding to it, and have gained more information about *Thais* since that time. This has been used in commentary and the paper has been extended.

Manuscript received July 2, 1979; accepted July 20, 1979.

## INTRODUCTION

Work was carried on from August 22, 1935, to April 15, 1936, at the Indian Pass Laboratory of the U.S. Bureau of Fisheries on Apalachicola Bay, Florida. It was planned as an integral part of the oyster pest investigation of the U.S. Bureau of Fisheries which extended from Massachusetts to Texas and ran from June 1935 to July 1936.

The objectives of these studies were to determine to what extent *Thais* is a pest; to study its distribution and life history; and to devise a means of control, if possible.

The work consisted of field studies in Apalachicola and nearby bays, but principally the former, and experiments and observations conducted in the laboratory. In the years after 1936, further observations were made in Texas, Louisiana and Mississippi.

## THE ANIMAL STUDIED

This snail is a prosobranchiate gastropod belonging to the order Stenoglossa. It was formerly considered to belong to the family Muricidae by taxonomists, but others separated the Purpuridae or Thaisidae from the larger group (cf. Clench 1947).

The species has been variously listed in the older literature as *Purpura haemastoma*, *P. floridana* and *P. h. floridana*. Johnson (1934) lists it as *Thais floridana floridana* Conrad. Clench (1947) considers that the United States specimens may be divided into two subspecies, *Thais haemastoma floridana* Conrad, which ranges from North Carolina around Florida to Pensacola and through the Indies to Venezuela, and *T. h. haysae* Clench, a large nodulose form living from western Florida to Texas. These subspecies are supposed to be separable generally on the basis of shell nodules (smooth to very rugged), and size. However, St. Amant (1938) found conchs in Barataria Bay which he could separate into these categories and Butler (1954) found both types in Pensacola Bay. He says that these differences will probably ultimately be shown to be environmental. Our own experience has been that there is no rhyme or reason to the distributions of these two supposedly different conchs along the Gulf coast. Conchs are variable on different reefs in the same bay and may be recognized as to reefs of origin, just as oysters are. In Apalachicola Bay in 1935, there were populations on some reefs which were no more rugose or nodulated than a *Polinices* shell, although they were not slick, while nodulated populations existed on other reefs in the same bay.

In commenting upon these differences, in an unpublished report submitted to the Bureau of Fisheries in 1936, the author said that they indicated one of two things: either the groups from different localities do not mix with other strains or, if they do mix due to relatively wide distribution of pelagic larvae, differences in local environments cause them to grow in different ways. The latter supposition is much more likely. Cook (1895) presented data showing differences between shells of a gastropod associated with locality difference.

The writer has gathered the impression that the amount of nodules present depends somewhat upon the size of the animal. There is a tendency for the *Thais* in the "Louisiana Marsh" region, east of the Mississippi River, to be larger and more rugose than those elsewhere; this is also a region where large oysters abound and today it is probably the largest natural oyster-producing ground on Earth.

Therefore, there seems to be no reason for assigning two subspecific names to the *Thais haemastoma* complex in the Gulf. Conrad's *floridana* is only given subspecific rank by leading American conchologists and according to Clench (1947) it is "exceedingly close to the typical form" (*haemastoma* of the Mediterranean, Africa, east and west coasts of South America, west coasts of Middle America and Mexico) from which it is said to be separable by color and being less nodulose. But since some of the northern Gulf *Thais* are as nodulose as any *haemastoma* there seems to be no good reason to adopt *floridana* either as a specific or subspecific name for this group. Very extensive statistical analyses, probably of larger collections than are now available anywhere, must be made before the situation becomes clear. Indeed this may not suffice and other procedures such as serological, chromosome analyses, soft anatomy and life history studies may also be necessary. Such an undertaking may not be considered worthwhile for a long time to come, if ever. In the meantime it would seem the remaining conservative course is to use the only indubitably valid name, *Thais haemastoma.*

### *External Anatomy*

The shell is a dextral, spirally coiled valve. There are seven whorls, the last and largest being known as the body whorl. Beginning near the apex and progressing spirally on the whorls is a double row of tubercles, leading to the aperture, which increase in size as they progress until they become blunt cones or nodules. They are much more pronounced in some animals than others and in some from other localities they are completely absent. The columella is straight and without a lumen. The aperture is prolonged as a short, open siphonal canal.

Like all members of the Stenoglossa, *Thais* has a long retractile proboscis containing the odontophoral apparatus and having the mouth opening at its extremity. The odontophoral mechanism of the *Thais* is doubtless similar to that of other prosobranchs, but it has not been described in print. Gunter (1936) analyzed radular movement of *Thais* and several other prosobranchs as a drilling mechanism.

Several members of the genus *Thais* are known as rock shells, presumably because they are often found on rocks. However, the name is also appropriate because the shells are so hard. They are quite difficult to break with a hammer even on a rock surface, and they are opened easily only by cracking them in a vise. Nevertheless, Butler (1954) says they are cracked and eaten by hungry stone crabs (*Menippe mercenaria*). The writer has observed the same thing and Powell and Gunter (1968) showed that *Menippe* would kill and eat *Thais* in laboratory aquaria.

In spite of their hardness, *Thais* shells are sometimes invaded by three kinds of shell-perforating organisms. These are the boring sponge *Cliona*, the boring clam *Diplothyra smithii* (*Martesia* of most authors), and polychaete worms, *Polydora* sp. There are also little patches of closely adherent, green alga on many *Thais* and quite often, one or more fairly large oysters of either *Crassostrea virginica* or *Ostrea equestris*, species found on the Gulf coast.

The siphon is a prolonged, roughly rectangular flap of the pallium leading out from the gill chamber, and is normally folded together by the animal to form a tube. The mantle or gill chamber contains the gill and the ctenidium near the siphon. On the right side is the anus and rectal

gland. This gland gives off a yellow mucous the function of which is unknown; it turns purple in sunlight. Before the days of the Greeks and Romans, the Minoans of ancient Crete used Mediterranean mollusks of the genus *Thais* and the related genera *Murex* or *Purpura*, to make the famous dye later known at Tyrian purple, which comes primarily from the rectal gland.

When extended, the pedal base of the snail is a broad, rectangular organ with the operculum on the posterior dorsal surface. The operculum completely closes the aperture when the foot is drawn in. It is made of thin, horny material. The nucleus of the operculum is lateral.

The two eyes are sessile on the outer side of the base of the nonretractile tentacles. They have not been studied histologically and their grade of complexity is unknown. The eyes of *Thais* are not very well developed and apparently they are of use only in distinguishing light from darkness or degrees of darkness.

The head consists, externally, mostly of a slightly raised portion bearing the tentacles. This part is not often exposed even when the animal is crawling about on solid surfaces. The tips of the tentacles, for about 3 or 4 mm, are smaller in diameter than the rest, and are retractile within the tentacles. They are black except at the very end and are probably light sensitive.

The pedal base is a light cream color and the upper surface of the flesh is a light, finely streaked brownish-grey. The shells are various shades of yellowish-brown.

The gonads are a thin sheet of tissue lying over the liver on the body coil. In the females they are of a pale yellow color tinted with orange, while in the males they are of a color best described as lavender-grey. These colors change as the breeding season approaches and become more vivid.

All animals, except a very few females, have an S-shaped penis attached slightly behind and to the right of the right tentacle. This organ was observed to be large in the males, while in the females it ranges from an almost indiscernable rudiment to a size nearly as large as that of the males in some individuals.

No sexual dimorphism could be discerned by general observation and several measurements made on the shell.

Large *Thais* approach 100 mm in length in Florida and Louisiana waters. The largest specimen on record seems to be one 103 mm long from Grand Bayou, Louisiana (Clench 1947). A group of 53 "large" conchs brought in from the oyster reefs of Mississippi Sound in February 1956 ranged from 72 to 96 mm in length and averaged 82.5 mm. After being dried in room air for 2 days, the weight of these animals ranged from 58 to 124 g, averaging 80.0 g.

## PREVIOUS WORK

Ritter (1896), Kibbe (1898) and Swift (1898) mentioned among their lists of oyster enemies on the Gulf coast, a snail which they called variously, drill, conch, whelk or borer. The specific name was not given by these Navy officers but it appears that their references were to *Thais*.

Moore (1899, p. 91) says that *Purpura* "causes considerable damage" on oyster beds in Louisiana. He placed several with oysters in aquaria but stated that they did not "molest them in any way." He says that *Thais* (*Purpura*) "is found everywhere on the oyster beds of Louisiana excepting the less saline waters," and that the fishermen held it responsible for the destruction of the oysters of Chandeleur Sound.

Moore (1907) later reported that *Thais* was not destructive on the oyster bottoms of Texas. This was an error. *Thais* causes as much damage in Texas as it does elsewhere.

Moore and Pope (1910) tried experiments by placing boxes of oysters and *Thais* together and boxes of oysters alone on oyster beds for over 2 months. When these were taken up it was found that only 2% of the spat survived and all upper valves of the dead spat which remained showed small round perforations, which were attributed to *Thais*. These workers also state that only spat were attacked and it is safe to say that adult oysters are not damaged due to their thicker shell.

Moore and Danglade (1915, p. 41) stated that they found "practically no oysters" killed by *Thais* in Lavaca Bay and that they, being essentially saltwater animals, are confined to the lower part of the bay.

Churchill (1920) gave a brief summary of information on *Thais* up to that time.

The paper of Burkenroad (1931) seems to be the only one in the literature up to then concerning this animal alone. His chief findings were that: (1) Both sizes of oysters are eaten, but the smaller ones are preferred. (2) Mussels (*Mytilus*) are preferred to oysters. (3) *Thais* seems to be unable to live in water of low salinities and its range therefore does not completely coincide with that of the mussel or the oyster. (4) During the breeding season *Thais* displays a strong negative geotropism so that it can be trapped at that time by driving stakes on the beds and taking them up after the animal has climbed them.

St. Amant's (1938) master's thesis said that adult conchs lived in water with a salinity of 20°/oo or higher. This was called the conch line. J. G. Mackin and the writer have found this line to be at about 18.0°/oo and that small *Thais* live beyond the line in water of lower salinity. St. Amant found that the snails became inactive when the temperature fell to 10°C. He found them scarce on mud bottoms. Oysters were said to be the chief food. Development of the early stages was mentioned and the incubation period within the egg capsules was said to be 10 to 12 days, after which the larvae hatched. The breeding season was recorded as early March to late July with a peak in April and May.

## BEHAVIOR OF *THAIS* IN THE LABORATORY

The writer has made many observations of *Thais* in the laboratory in Florida, Texas, and Mississippi over many years. The general conclusions are drawn together in the

following account. I am indebted to Ms. Judy Williams and Miss Kay McGraw for help in the laboratory and to many zoologists for long discussions, chiefly D. W. Menzel, Lyle St. Amant, J. G. Mackin, A. S. Pearse, Frank W. Weymouth, William J. Demoran and Sewell Hopkins.

When first brought into the laboratory the animals are closed, sometimes completely, but usually with the siphon extending from under the operculum into the siphonal canal. When placed in tanks or jars with running sea water they usually opened and attached themselves by the foot to the substrate in less than 30 minutes. Those that did not open were dead or moribund. In cool weather animals lived in air over a week, if not exposed to the sun. In warm weather they died in 2 or 3 days under the same conditions.

When placed in the air *Thais* would attach to the substrate but could move very little if it was dry. They seemed to live and move about indefinitely on water tables in which the foot was submerged in only a millimeter or so of running sea water.

### *Action of the Foot*

The foot of *Thais* progresses by small waves which start at the rear and move forward. There is an unseen division mark along the center of the foot and thus there are separate waves for each side. These start alternately and there are two waves on either side at one time. They do not extend at right angles across the foot, but are diagonal with the inner ends ahead of the lateral ends. Foot waves of gastropods are of various types and a classification of them was introduced by F. Vles, the French zoologist, in the early 1900s. According to this classification the foot waves of *Thais* are of the direct, ditaxic, alternate, diagonal type, which is virtually self-explanatory. It has been observed that the anterior margin of the foot is made up of a distinct band of tissue which undergoes a forward rippling motion not connected with the pedal waves.

*Thais* can twist or turn the pedal base in any direction, but none was seen to crawl backwards.

By shooting a strong stream of water under the foot, the writer has shown that the animals can cling to the sides of a glass jar with less than one fifth of the total area of the foot attached. The powers of suction and attraction to the substrate are local. This ability and the fact that *Thais* can turn and twist in any direction enables it to crawl about over oyster bars with ease.

When feeding, *Thais* folds the front part of the foot so that it forms a short enclosed tube at its anterior portion through which the proboscis is extended. Animals in the natural state were not observed to feed with the proboscis unprotected or extended so that it could be seen, although it is possible they do, for they could be induced to do so as described below.

*Thais haemastoma* seems to be much more sensitive with regard to its proboscis, mouth and drilling apparatus than *Melangena corona* (Gunter and Menzel 1957). The latter gastropod seems to attack its victims when they are lively and far from dead, and lies about feeding with the whole proboscis extended and exposed. In contrast, *Thais* is secretive and protective and in natural life seems never to have its proboscis exposed, but either retracted or covered by the foot.

Demoran and Gunter (1956) thought to remove the proboscis of *Thais* and see how they would handle oysters then. To our considerable surprise this whole complicated apparatus was regenerated in 3 weeks time and the conchs went about cutting the edge of the oysters' shells and killing them just as before.

The pedal groove runs transversely across the anterior margin of the foot. In *Buccinum* and *Murex* this is the opening for glands which secrete the egg capsules (see Fretter 1941); the same is true for *Purpura* as shown by Pelseener (Dakin 1912). Egg laying in *Thais* was not observed.

The foot of *Thais* apparently contains taste buds, as was shown for *Busycon* and *Ilyanassa* by Copeland (1918).

In short, the foot functions in five known ways, namely, in locomotion, as an organ of taste, in protection of the proboscis, and probably in formation of egg capsules. It also seems to act as an accessory boring organ as shown below.

### *Use of the Sense Organs*

Copeland (1918) has shown that in *Busycon* and *Ilyanassa* the osphradium is the organ of smell. This seems to be true of *Thais* also. When the animal is crawling about the siphon is continually moved from side to side or up and down so that it seems to be testing the water. In all probability water drawn into the siphon is "smelled" in the gill chamber by the osphradium.

Copeland (1918) has described the reactions of *Busycon* and *Ilyanassa* to food. There is a regular sequence of events which the writer has observed to be essentially the same in *Fasciolaria gigantea, Busycon perversum, Melongena corona* and *Thais haemastoma*. Although Copeland has made no such claims, these observations lead this writer to believe that the responses to food described by Copeland for the two above species are common to most carnivorous gastropods.

These reactions may be described as follows:

If a drop of oyster juice is placed on the tip of the siphon it contracts quickly and sharply. The animal then comes farther out of the shell and waves the siphon from side to side. If no further stimulus is given the animal begins to crawl about, waving the siphon meanwhile. If the stimulus came from one side the snail moves to that side.

If the foot, head or tentacles are touched with a piece of oyster meat or a drop of juice, they recoil in the same manner and then the animal begins to move about. If the meat is left in contact with the foot and held so that the animal can feel it, but not fold the foot around it, the proboscis is slowly projected until it touches the meat and begins to rasp. If the meat is slowly moved down the side

Bay were sieved through three meshes of wire. The first was ordinary poultry wire, the second was galvanized wire mesh and the third was ordinary screen wire. This work was carried on from December 1935 to March 1936. No small *Thais* except the five listed above were found, although hundreds of small gastropods were caught, some of them being as small as 2 mm in length.

The fact that all the young caught were taken on the bars seems to indicate that this is their natural habitat. Isolated specimens of large *Thais* have been reported from 13, 15 and 50 miles in the open Gulf. There is no explanation of their scarcity, unless it is that the 1935 breeding season was unsuccessful. Reliable men who have worked on the bay for years said that in some years reproduction does not take place and that the 1935 season was one of comparative scarcity of eggs.

The gonads of both males and females began to thicken and enlarge in January. Previous to that time the gonads had been only thin strips of tissue over the liver coil. By the end of March 1936, the gonads were about 2 mm thick and had changed color in both sexes. Those of the female were light cream color and those of the males were of a waxy yellowish-orange color.

Dr. A. S. Pearse (personal communication) observed the animals breeding in June of 1935. The last day he observed animals laying eggs was on June 19. He observed the animals congregated in bunches so that in some localities on St. Vincent's Bar a half bushel of *Thais* were tonged in one bushel of total tonged material.

## SALINITY EXPERIMENTS

Four sets of salinity experiments were carried out.

In experiment 1, six sets of glass dishes were used containing two *Thais* and 1 liter of stagnant water. The experiments were started on November 19, 1935. The salinities of water in sets of dishes 1 to 6, respectively, were: distilled, 5.80, 10.93, 20.45, 30.59 and 34.19°/₀₀. The last was the same as the running sea water of the laboratory from which the animals were removed.

Animals in sets 5 and 6 attached in 20 minutes. Those in set 4 opened in an average of 5 hours. No animals in the first three sets (salinities: distilled, 5.80 and 10.93) attached at all. On November 24, one animal from each jar of sets 1 to 3 were placed in running sea water of the laboratory which was approximately at a salinity of 30.99°/₀₀. These all revived in 6 hours. On the tenth day one animal from each of the same sets were placed in running sea water at a salinity of approximately 25.00°/₀₀. The animal from set 3 (salinity 10.93) revived, while the other two did not. On the thirteenth day all of the single remaining animals in set 3 were dead.

On the tenth day one animal in set 5 died from unknown causes. All other animals in sets 4 to 6 remained attached and sensitive to touch throughout the experiment and were discarded on November 28.

The temperatures and pH of the water in each jar were taken 18 times during the experiment. At the beginning of the experiment the pH of sets 1 to 6 was: 6.8, 7.3, 7.4, 7.7, 7.8 and 7.9, respectively. As time passed, the pH in the lower sets rose and that of the higher sets fell and on November 28, ranged between 7.4 and 8.0, averaging 7.6 for all jars.

Unfortunately temperatures could not be controlled. At the beginning of the experiments they ranged from 16.8 to 17.0°C and later rose to as high as 22.4°C; then fell to 9.2 and rose again to 19.4. Nevertheless, they were comparable from jar to jar and did not differ more than 0.8°C at any one time.

Animals in a moribund condition were tested for sensitivity by pricking the siphon. If there was no reaction they were placed in sea water, where they sometimes revived. The best criterion of death was the strong putrid smell, apparently emanating from the rectal gland, which set in soon after death. No animal giving this smell ever revived in sea water although they seemed otherwise to be in the same condition as some animals which did revive.

This experiment shows that *Thais* removed from water of comparatively high salinity (35.00°/₀₀) can be placed suddenly in water as low as 20.45 and after accustoming themselves, live in it. Also *Thais* removed from the same water and placed in water lower than salinity of 10.93°/₀₀ cannot accustom themselves as shown by the fact they remain closed, and die. Nevertheless, they die very slowly and can survive in distilled water for at least 10 days.

In experiment 2, eight battery jars were used. One liter of water and two *Thais* were placed in each. The latter were removed from water of salinity 32.90°/₀₀. The salinity of water in jars 1 to 8 was: distilled, 5.25, 10.05, 12.12, 14.00, 15.96, 19.93 and 32.90°/₀₀, respectively. All jars were aerated by glass and rubber tubing leading off from a small electric air pump.

In jar 8, both animals opened in 40 minutes and remained so throughout the experiment.

In jar 7, one opened in 6 hours and the other in 2 days. The latter animal closed in 8 days and was dead in 11 days. The remaining one closed in 15 days probably because multiplication of bacteria in the water.

In jar 6, one *Thais* opened in 18 hours and the other in three days. They remained attached throughout the experiment although at the end one had the foot partly folded.

Animals in jar 5 opened in 2 and 7 days, respectively, and remained so throughout the experiment.

In jar 4, one specimen opened in 5 days and the other in 9 days. The latter partly folded its foot after 5 days.

In jar 3, both animals opened in 7 days but partly closed two days later and remained that way.

Animals in jar 2 remained closed. One revived in 12 days after being placed in sea water of salinity 27.59°/₀₀. The remaining one was dead by the fifteenth day.

Animals in jar 1 did not open. One revived after 10 days when placed in water of salinity 28.86°/₀₀. The other was dead on the twelfth day.

On the eighth day of the experiment, it was found, due to evaporation and possibly the loss of salts by the animals, that the salinities of the jars had risen. They were in jars 1 to 8, respectively: 1.00 (estimated), 7.21, 11.92, 14.51, 16.42, 18.67, 22.11 and 35.86°/oo. They were changed in order to: distilled, 5.26, 10.01, 12.29, 13.99, 16.16, 19.79 and 27.83°/oo. This apparently had little effect on the experimental animals for their behaviour was the same after as it was before the change.

The experiment was stopped on December 18. At this time six of the remaining animals in the last five jars were attached. Two had the foot folded but not closed and one was closed tight.

The pH and temperatures were taken 13 times in all. The temperatures changed from 19.8 to 10.0°C and back to 17.1°C. There was no difference between jars greater than 0.5°C at any one time. The pH at the beginning of the experiment ranged from 6.4 in the first jar to 8.0 in the last one. The pH in the lower jars rose so that after the sixth day it fluctuated between 7.6 and 8.4 for all jars.

This experiment shows that *Thais* removed from water of salinity around 33.00°/oo can accustom themselves to water of salinity as low as around 12.00°/oo after several days. It also shows that the time taken for animals to accustom themselves roughly increases directly as the salinity decreases to the lethal or lower toleration point. Animals were not able to tolerate water of a salinity of 10.5°/oo and below, but could live as long as 10 days even in distilled water.

It was found from the above two experiments that the lower salinity toleration point for *Thais* from water of salinity 32.00 to 34.00°/oo, was around 10.00 to 11.00°/oo. Another experiment was devised to determine this point more exactly. This expectation was not realized, but another discovery of possibly more importance was made, as described below.

The experiment was started on January 28, 1936. Three sets of two battery jars each were used. These each contained 1 liter of aerated water. The salinities from sets 1 to 3, respectively, were: 8.96, 10.03 and 11.06°/oo. Two *Thais* were placed in each jar. One animal in set 1 and one in set 2 did not open at all and were dead in 8 and 9 days, respectively. Contrary to what was expected, all ten other animals opened in from 1 hour to 2 days and remained so for 21 days when the experiment was stopped. The average time taken for the animals to open in each pair of jars from 1 to 3, respectively, was 24, 5 and 2 hours. It is seen that time increases as salinity decreases. The temperature and pH of the water was taken 21 times during the 21 days the experiment was run. The water was changed 14 times. The salinity of that used for changes for sets 1 to 3 fluctuated between 9.00 to 9.16, 9.99 to 10.28 and 11.04 to 11.15°/oo, respectively. The pH varied from 7.2 to 8.0. The temperature fluctuated between 15.5 and 21.8°C. The greatest difference between jars at any one time was 0.7°C.

Previous to this experiment the animals used had been kept in the running sea water of the laboratory. On January 13, this water dropped below salinity 20.00°/oo for the first time in 3 months. It was at 12.83 and down to 4.38 on January 28. The latter figure was the salinity from which the experimental animals were removed. The evident explanation then for the results obtained is that the *Thais* had somewhat acclimated themselves to lowered salinities in the laboratory, so that their toleration or lethal point of low salinities had fallen still lower. Federighi (1931a) found similar results working on *Urosalpinx cinerea*. He found that these animals from one locality died at a higher salinity than did those from other localities where the average environmental salinities had been lower than in the first locality.

On February 17, the foregoing experiment was stopped and the following one was started. It was really a continuation of the former experiment. All animals from each pair of jars were placed in one jar, making 3, 3 and 4 in jars 1, 2 and 3, respectively. One liter of fresh water of salinity 8.04, 9.04 and 10.04°/oo was placed in jars 1 to 3, respectively. This water was changed using the same salinities on the third and on the fourth days. On the fifth day, the water was changed to salinities of 7.00, 7.85 and 9.04°/oo, respectively. On the eighth day, this water was changed. On the ninth and fourteenth day, 100 cc of solution were removed from each jar and 100 cc of tap water added. On the fifteenth day, 150 cc of fresh water were added to each jar.

The temperature of the water during the experiments varied between 12.4 and 24.0°C. The pH varied from 7.4 to 7.9 up to the fifteenth day when the water had turned milky. At this time pH for all three jars averaged 8.3. No water was added thereafter.

All animals remained attached and opened up to the fourteenth day. From that time on the foot was partly folded. One animal in jar 3 was dead on the twenty-third day. Unfortunately, the writer was away from the laboratory at that time and when he returned on the twenty-fifth day the water was foul and the other three animals were dead, proably more from this cause than from the low salinities. Results from this jar had to be disregarded. On the same day, one animal in jar 1 was dead. On the thirtieth day, all animals in jar 1 and two of those in jar 2 were dead. The salinities of these jars were 6.22 and 6.88°/oo, respectively. The remaining animal in jar 2 was sensitive to pricking 4 days later when, due to evapoation, the salinity of the water had risen to 7.41°/oo. This was lowered to 5.75°/oo and the next day the animal was dead.

This experiment shows that *Thais* can accustom themselves to and live in water of salinities as low as 7.00°/oo if it is lowered slowly, but died when the salinity reaches a point around 6.5°/oo.

## FIELD EXPERIMENTS

On December 10, 1935, boxes containing *Thais* were placed at six stations. These stations were on Hiles' Shallow Bar near Indian Pass, Picolyne Bar, north end of St. Vincent's

Bar, south end of St. Vincent's Bar, Platform Bar and a small bar in East Bay. Each box was constructed of poultry wire over a wooden frame. Two were put down at each place. One of these contained 8 *Thais* and the other contained 8 *Thais* and 25 adult oysters. These were visited an average of five times each between December 10, 1935 and February 26, 1936.

About January 13, flood waters from rivers above Apalachicola came into the bay and the salinities as a whole took a precipitous drop. Before this date, 10 oysters died from natural causes or were eaten by the *Thais* within the cages. No *Thais* died. From January 13 to February 26, when the salinities were low, 4 oysters died and 36 *Thais* died. Twenty-five of the *Thais* casualties were on the north and south of St. Vincent's Bar and East Bay which were areas of the lowest salinity. Twenty-two of the dead *Thais* were in boxes containing oysters so it cannot be said that they starved to death.

The bottom salinities taken from these stations dropped to a little above 9.0°/₀₀.

This experiment apparently proves that under natural conditions on the beds, oysters will survive lower salinities than *Thais* so that the range or habitat of oysters is, or may be in part, in areas where the average salinities are lower than *Thais* can tolerate.

This fact was also proven still more conclusively by natural events, for on February 17, 1936, *Thais* on St. Vincent's Bar were seen to be dying. Freshly dead, undecayed animals were taken at this time. From then until February 27 they died in great numbers. On this last date, two apparently moribund animals revived when brought to the laboratory. Since February 27, all *Thais* shells taken on this bar have been empty. Apparently, *Thais* has been exterminated here by fresh water, while most of the oysters lived, although there were some casualties. In March 1936, 41 bushels of material were tonged from 16 bars. *Thais* were taken only on Hiles' Shallow Bar near Indian Pass and it seems that this was the only place where they were present in Apalachicola Bay. Events of that nature seem to happen over and over on the Gulf coast, and result in the killing out of *Thais* and survival of oysters in low-salinity waters following high water or flood periods. They are particularly noticable in Mississippi and Louisiana (Viosca 1928, Gunter 1953).

## ENEMIES

The stone crab, *Menippe mercenaria*, can kill and devour *Thais* as noted above (Powell and Gunter 1968). Butler (1954) has stated that hermit crabs kill these conchs and Percy Viosca (personal communication) told the writer that several hermit crabs gathered around *Thais* and pinched their tentacles until they bled to death, after which they pulled the body from the shell and took it for their own.

## MISCELLANIA

Gastropod mollusks have existed since the upper Cambrian. As stated previously in this paper, the radula and, by the same token, the odontophore are present in every molluscan class except the Pelecypoda. Even so, as Krutak (1977) has pointed out, the radular teeth of gastropods have not been reported as fossils. This is quite strange insofar as the gastropod mollusks are organisms of vast abundance in the seas. This puzzle is explained if it is assumed that the conodonts, a group with no-known relatives or relations, are really the radular teeth of gastropods and other mollusks, extending back almost to the beginning of animal fossils in the Cambrian age.

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


## A Study of Four Oyster Reefs in Mississippi


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DOI: 10.18785/grr.0603.06

*Gulf Research Reports*, Vol. 6, No. 3, 261–265, 1979.

# A STUDY OF FOUR OYSTER REEFS IN MISSISSIPPI

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*ABSTRACT* A study of four oyster populations in Mississippi over 13 months (May 1978–May 1979) indicates that although oysters are sexually developed during most of the year (10 months), setting was variable in intensity, dependent upon location, and limited in all cases to one or two months. Mortality was variable, dependent upon location and was attributed to high predation at one station and to harvesting and fresh water at the other stations studied. Suggestions for management are discussed.

## INTRODUCTION

The oysters and the oyster industry of Mississippi have been the subjects of numerous investigations dating back to the early part of the century. However, data that are available consist of oyster bottom surveys and studies of setting. The densities of oysters on various reefs have been mentioned (Moore 1913, Engle 1948, MacKenzie 1977). An evaluation of different cultch materials (Veal, Brown, and Demoran 1972) conducted during 1971 and 1972 was invalidated by the lack of a spat set. During seven months of 1972, spat setting was monitored on fouling plates at one station in Bay St. Louis, MS (Haburay 1977). Setting was monitored on fouling plates at five stations in Mississippi Sound for one year (October 1976–October 1977) and that same study (McGraw, personal communication) provided information on the growth rates of oysters. However, only one of the five stations was near a commercial reef (Biloxi Bay).

With recent interest in managing, developing and exploiting oysters, this lack of basic information has become apparent. This study was conducted to determine condition, setting, growth and mortality of oysters at four reefs in Mississippi.

## MATERIALS AND METHODS

One-cubic-foot samples of reef material were collected monthly for 13 months at four stations: a lagoon at Horn Island, Graveline Bayou, a closed reef in Biloxi Bay, and a tonging reef at Pass Christian. The oysters at Horn Island are harvested publicly for recreation; the reefs at Graveline and Biloxi Bay are dredged for relaying and the reef at Pass Christian is harvested commercially. The Graveline and Pass Christian samples were dredged, while the Horn Island and Biloxi Bay samples were handpicked in shallow water. The number and size of all live oysters were determined and enumerated into four 25-mm-size classes: spat, seed, juvenile, and market sizes (Hofstetter 1977). The number of fresh single valves and boxes was determined and the percent of dead shell material was calculated. The average condition index was calculated according to the procedure of Hopkins (1949) with the shell cavity volume being determined according to the procedure of Galtsoff (1964). Gonadal development was determined on ten oysters by noting the condition of a gonadal smear. Hydrographic data, including temperature determined to the nearest degree Celsius and salinity determined to the nearest ppt with an American Optical total solids refractometer, were recorded for each station monthly.

Manuscript received August 31, 1979; accepted September 28, 1979.

## RESULTS

Graveline oysters had the highest condition index (Table 1) throughout most of the study while Horn Island oysters had the lowest condition. Generally, oysters for all four stations had similar seasonal trends. Condition was high during May of both years (1978, 1979). However, values were also high during November 1978 and March 1979 for all stations. Values were low during the summer of 1978 and again during January 1979.

Sexually developed oysters were found during ten months of a yearly period for at least one of the four stations (Table 1). January and February were the only months for which no sexually developed oysters were found at any station. Horn Island oysters were developed the greatest number of months (10 of 13) while oysters from Biloxi Bay and Graveline were developed during 8 of 13 months sampled.

Setting of larvae, based upon spat set on shells, was variable in intensity, dependent upon location and limited to a couple of months. Spat were first noticed during July at Pass Christian with a peak of setting during August. Oysters at Graveline Bayou did not set until November with a peak showing up in the December sample. Setting was most pronounced at Horn Island with a peak during August. An additional set occurred during November at that station. A very low set occurred during August at Biloxi Bay.

Growth of size classes was difficult to follow at Biloxi Bay due to the insignificant set, and at Graveline due to the late set in 1978. Growth of oysters at Horn Island was faster than growth at Pass Christian. Oysters which set during August at Horn Island were seed size in 5 months and had started to show up in the juvenile size class in 9 months (Table 2). Oysters which set during July at Pass Christian were seed size in 6 months and were showing up in the

TABLE 1.

Average condition index and percent sexually developed oysters based upon ten oysters from four reefs in Mississippi over a 13-month period.

| Station | 1978 May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | 1979 Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Condition Index | | | | | | | |
| Biloxi Bay | 7.83 | 6.40 | 4.55 | 5.68 | 5.31 | 6.04 | 8.53 | 7.74 | 4.72 | 7.65 | 11.80 | 9.10 | 13.34 |
| Graveline | 7.46 | 7.19 | 5.68 | 4.68 | 6.28 | 10.01 | 16.80 | 13.54 | 11.19 | 13.09 | 16.80 | 10.60 | 11.69 |
| Pass Christian | 8.24 | 4.74 | 4.56 | 5.59 | 5.22 | 5.51 | 12.13 | 8.08 | 11.00 | 9.43 | 17.00 | 10.00 | 9.78 |
| Horn Island | 6.60 | 6.63 | 4.56 | 3.97 | 6.09 | 4.04 | 7.21 | 7.78 | 7.78 | 7.19 | 8.80 | 8.34 | 6.09 |
| | | | | | | Percent Sexually Developed Oysters | | | | | | | |
| Biloxi Bay | 90 | 100 | 100 | 90 | 70 | 10 | 0 | 0 | 0 | 0 | 0 | 70 | 80 |
| Graveline | 30 | 100 | 80 | 100 | 80 | 40 | 0 | 0 | 0 | 0 | 0 | 10 | 88 |
| Pass Christian | 80 | 100 | 50 | 80 | 70 | 50 | 20 | 40 | 0 | 0 | 0 | 90 | 100 |
| Horn Island | 40 | 50 | 90 | 100 | 100 | 20 | 0 | 20 | 0 | 0 | 0 | 90 | 90 |

TABLE 2.

Size frequency distribution of live oysters contained in a standard (1 cubic foot) dredge sample.

| Percent Size Distribution | 1978 May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | 1979 Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Biloxi Bay | | | | | | | |
| Spat (0–25 mm) | 1.9 | 2.0 | 1.7 | 7.0 | 1.0 | 2.9 | 3.6 | 6.0 | 1.8 | 1.2 | 2.1 | 1.7 | 4.8 |
| Seed (26–50 mm) | 63.4 | 23.0 | 33.5 | 18.5 | 16.0 | 15.1 | 16.5 | 24.0 | 17.2 | 12.5 | 45.7 | 21.1 | 20.8 |
| Juvenile (51–75 mm) | 23.8 | 35.0 | 39.1 | 57.3 | 44.3 | 52.7 | 44.4 | 32.0 | 38.4 | 43.4 | 44.3 | 38.6 | 48.8 |
| Market (75 mm) | 12.9 | 40.0 | 25.7 | 17.2 | 38.7 | 29.3 | 35.5 | 38.0 | 42.6 | 42.9 | 7.9 | 38.6 | 25.6 |
| | | | | | | Graveline Bayou | | | | | | | |
| Spat (0–25 mm) | 1.4 | 0.8 | 1.2 | 8.2 | 8.3 | 1.1 | 56.3 | 64.8 | 49.8 | 53.9 | 59.9 | 55.0 | 56.9 |
| Seed (26–50 mm) | 21.3 | 13.3 | 25.9 | 17.0 | 19.0 | 46.3 | 14.7 | 9.3 | 14.8 | 10.4 | 10.1 | 11.3 | 14.1 |
| Juvenile (51–75 mm) | 28.1 | 40.7 | 31.3 | 32.7 | 31.0 | 37.9 | 11.3 | 14.6 | 15.5 | 11.4 | 11.9 | 14.1 | 14.0 |
| Market (75 mm) | 49.2 | 45.2 | 41.1 | 42.1 | 41.7 | 14.7 | 17.7 | 11.3 | 19.9 | 24.3 | 18.1 | 19.6 | 15.0 |
| | | | | | | Pass Christian | | | | | | | |
| Spat (0–25 mm) | 6.4 | 1.9 | 41.5 | 51.8 | 40.9 | 26.2 | 19.4 | 15.3 | 14.3 | 10.7 | 12.9 | 13.5 | 7.7 |
| Seed (26–50 mm) | 28.2 | 23.5 | 11.8 | 9.4 | 19.8 | 5.0 | 9.2 | 13.3 | 73.2 | 16.6 | 29.5 | 18.9 | 27.8 |
| Juvenile (51–75 mm) | 30.9 | 26.1 | 17.8 | 17.6 | 26.6 | 18.8 | 10.2 | 16.3 | 7.2 | 19.8 | 37.6 | 15.3 | 28.9 |
| Market (75 mm) | 34.5 | 48.5 | 28.9 | 21.2 | 12.7 | 50.0 | 61.2 | 55.1 | 5.3 | 52.9 | 20.0 | 52.3 | 35.6 |
| | | | | | | Horn Island Lagoon | | | | | | | |
| Spat (0–25 mm) | 34.9 | 12.9 | 19.1 | 73.0 | 46.7 | 56.0 | 63.1 | 35.2 | 52.5 | 56.0 | 50.2 | 51.5 | 29.5 |
| Seed (26–50 mm) | 48.3 | 73.9 | 62.7 | 25.0 | 29.0 | 19.0 | 20.6 | 31.8 | 39.4 | 32.2 | 46.1 | 22.7 | 40.8 |
| Juvenile (51–75 mm) | 13.6 | 10.8 | 17.1 | 2.0 | 18.3 | 7.0 | 13.9 | 26.5 | 7.6 | 11.0 | 3.5 | 17.7 | 22.1 |
| Market (75 mm) | 3.2 | 2.4 | 1.2 | 0.0 | 6.0 | 17.7 | 2.4 | 6.5 | 0.5 | 0.8 | 0.2 | 8.1 | 7.6 |

juvenile size class in 10 months. The November set of oysters at Horn Island had reached seed size in 4 months.

Horn Island contained the fewest marketable oysters, while Pass Christian had the most market-size oysters (Table 2). The greatest number of marketable oysters was typically found during the fall months. Graveline Bayou was depleted of marketable oysters during October due to dredging.

The amount of dead shell was high for Pass Christian, but the most dead shell occurred at Graveline after it was dredged. Horn Island contained almost no dead shell material (Table 3).

Monthly mortality was high for Horn Island and Pass Christian (Table 4). Horn Island oysters experienced high mortality during June, July, August, January, March and April. Pass Christian oysters experienced high mortality during October, November, December and January, and again during March, April and May. Graveline oysters experienced a high mortality during October, while the highest mortality for Biloxi Bay oysters was during August.

The highest temperature (34°C) was recorded for Biloxi Bay whereas the lowest temperature (6°C) was recorded for the lagoon at Horn Island (Table 5). The highest recorded salinity (32 ppt) was for Horn Island while fresh water occurred at Graveline and Pass Christian. The lowest salinity recorded for Biloxi Bay was 4 ppt and the lowest salinity recorded for Horn Island was 10 ppt.

## DISCUSSION

The oyster population at Horn Island should be considered marginally harvestable. Reproductive potential was greatest at that station with two sets of spat occurring during the year, but there was not much cultch for the spat to set on. That resulted in the elongated shells and large clusters of oysters characteristic for areas of soft, muddy bottoms. Oyster growth in the lagoon was rapid but there were few market-size oysters, indicating a high natural predation and mortality. Oyster drills were probably the major cause of mortality. The protozoan parasite *Perkinsus marina*, responsible for oyster mortalities in areas of high salinity, especially during warm months of the year, was not prevalent during this study (Ogle, unpublished manuscript). The lagoons of Horn Island could be evaluated as spat-collecting areas utilizing artificial spat collectors.

The oysters at Graveline were generally the best oysters in Mississippi during this study period. The great number of large-sized oysters and their good condition was offset only by their being in an area closed to harvesting. The area was last harvested during February 1974 (W. J. Demoran, personal communication). Harvesting of the bayou during October of this study period for relaying of the oysters afforded the author the opportunity to investigate the effects of dredging on a reef and the effect of relaying oysters to new beds (Ogle 1979). Dredging of the bayou reduced the number of adult oysters and increased the percentage of dead shell, as would be expected. The highest monthly mortality was also recorded during the month that dredging occurred. These effects were offset by an excellent set of spat the month following dredging. Graveline Bayou, being protected from adverse weather and accessible to small craft, would make an excellent tonging reef. Consideration should be given to eliminating the sources of pollution into the bayou. This area would then serve eastern Mississippi, which presently has no commercial open oyster reefs.

Biloxi Bay, another closed oyster area, was dredged for relaying oysters during September and October. Dredging occurred adjacent to the sampling station, so effects of dredging were not recorded in this study. Biloxi Bay has been heavily dredged during the past several years. There was no significant spat set during this study and growth is known to be slow in this area, requiring 2 to 2½ years to produce market-size oysters (Ogle, unpublished data). The oyster bottom should be resurveyed to insure that it is not being overharvested and restrictions placed on the taking of oysters from this area.

Pass Christian was the only commercially harvested reef in this study. Harvesting occurred from September until April with heaviest tonging during October, November, December and January—months for which mortalities were also high. Interestingly, these were also months with the highest percent of marketable oysters. Mortalities during March, April and May were attributed to low-salinity waters from the flooding of the Pearl River and the opening of the Bonnet Carré Spillway on April 16, 1979. Should fresh water persist and mortality increase, planting of seed oysters may be required.

This study should be considered preliminary due to its limited scope and duration. In order to study the dynamics of a population adequately, especially oysters which require 2 years to reach a marketable size, several year classes should be followed over a period of several years. In addition, only four reefs were studied. Sampling should be expanded to cover all the major reefs in Mississippi. Because of the nonrandom nature of oysters on bottoms, the use of a standard volume sample only provided an indication of population dynamics. These data can then be used with surveys of the extent of oyster bottoms to estimate total oyster populations. The last survey of oyster reefs in Mississippi was completed in 1977 and should continue to be updated periodically.

## ACKNOWLEDGMENTS

I would like to thank Mr. John Supan, who collected most of the samples in this study, and Ms. Kathy Flurry who worked up those samples.

TABLE 3.

Composition of a standard (1 cubic foot) dredge sample.

| | 1978 | | | | | | | | 1979 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| **Biloxi Bay** | | | | | | | | | | | | | |
| No. live | 101 | 198 | 179 | 157 | 199 | 205 | 169 | 188 | 162 | 128 | 140 | 171 | 125 |
| No. boxes | 5 | 22 | 37 | 57 | 14 | 17 | 22 | 15 | 16 | 14 | 9 | 14 | 13 |
| No. valves | 17 | 11 | 48 | 60 | 3 | 6 | 26 | 17 | 9 | 7 | 6 | 11 | 11 |
| % Dead shell | 50.0 | t* | 16.7 | 16.7 | t | 4.0 | 8.3 | 8.3 | 4.2 | t | t | 12.5 | 50.0 |
| **Graveline Bayou** | | | | | | | | | | | | | |
| No. live | 142 | 135 | 166 | 159 | 168 | 95 | 300 | 398 | 291 | 202 | 277 | 327 | 266 |
| No. boxes | 16 | 15 | 10 | 4 | 11 | 2 | 6 | 12 | 15 | 22 | 8 | 15 | 9 |
| No. valves | 32 | 28 | 38 | 33 | 19 | 89 | 88 | 60 | 38 | 36 | 30 | 11 | 12 |
| % Dead shell | 9.0 | 8.3 | 17.0 | 8.0 | 4.0 | 58.3 | 41.6 | 25.0 | 25.0 | 33.3 | 25.0 | 25.0 | 34.3 |
| **Pass Christian** | | | | | | | | | | | | | |
| No. live | 110 | 157 | 135 | 245 | 196 | 80 | 108 | 98 | 56 | 121 | 85 | 111 | 90 |
| No. boxes | 3 | 10 | 2 | 18 | 8 | 30 | 46 | 40 | 20 | 15 | 7 | 25 | 34 |
| No. valves | 38 | 41 | 60 | 65 | 79 | 42 | 67 | 50 | 49 | 17 | 63 | 18 | 7 |
| % Dead shell | 25.0 | 20.8 | 50.0 | 41.6 | 50.0 | 33.0 | 17.0 | 33.0 | 42.0 | 16.7 | 50.0 | 33.3 | 50.0 |
| **Horn Island Lagoon** | | | | | | | | | | | | | |
| No. live | 469 | 372 | 346 | 697 | 345 | 425 | 846 | 381 | 620 | 763 | 864 | 260 | 569 |
| No. boxes | 69 | 169 | 93 | 191 | 19 | 37 | 68 | 62 | 400 | 109 | 226 | 83 | 94 |
| No. valves | 5 | 4 | 10 | 9 | 7 | 4 | 7 | 8 | 3 | 8 | 5 | 6 | 1 |
| % Dead shell | t | t | 4.0 | t | t | t | t | t | t | t | t | t | t |

*t — trace of shell

TABLE 4.

Percent monthly mortality based upon fresh boxes and valves contained in a standard (1 cubic foot) dredge sample.

| | 1978 | | | | | | | | 1979 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| Biloxi Bay | 11.8 | 12.2 | 25.4 | 35.6 | 7.2 | 8.9 | 17.2 | 11.1 | 11.2 | 9.4 | 7.9 | 10.2 | 12.9 |
| Graveline | 18.4 | 17.7 | 14.9 | 11.4 | 10.9 | 32.8 | 14.3 | 9.5 | 10.5 | 7.9 | 7.6 | 5.9 | 5.3 |
| Pass Christian | 16.7 | 16.3 | 19.1 | 17.0 | 19.5 | 38.9 | 42.4 | 39.8 | 44.3 | 16.3 | 31.2 | 23.4 | 29.4 |
| Horn Island | 13.2 | 31.5 | 22.0 | 21.9 | 6.1 | 8.4 | 7.8 | 14.8 | 24.5 | 12.9 | 20.9 | 24.8 | 14.2 |

TABLE 5.

Temperature (°C) and salinity (ppt) determined monthly for four stations in Mississippi over a 13-month period.

| | 1978 | | | | | | | | 1979 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| **Temperature; Salinity** | | | | | | | | | | | | | |
| Biloxi Bay | 29; 6 | 34; 6 | 32; 8 | 29;16 | 26;18 | 23;22 | 18;26 | 11;20 | 7;16 | 13; 4 | 22; 4 | 20;10 | 23; 8 |
| Graveline | 22;18 | 30; 6 | 32;11 | 28;16 | 25;19 | 23;24 | 17;21 | 11;12 | 8;15 | 10; 2 | 14; 5 | 19; 0 | 25; 2 |
| Pass Christian | 22;17 | 28;12 | 28;18 | 28;14 | 27;18 | 23;18 | 17;18 | 11;15 | 10;16 | 15; 5 | 19; 5 | 20; 5 | 26; 0 |
| Horn Island | 24;16 | 30;12 | 24;22 | 30;25 | –;22 | 14;28 | 19;32 | 12;24 | 12;26 | 6;11 | 16;14 | 25;10 | 26;13 |

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


## Marine Fishes of Panama as Related to the Canal


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DOI: 10.18785/grr.0603.07

*Gulf Research Reports*, Vol. 6, No. 3, 267–273, 1979.

# MARINE FISHES OF PANAMA AS RELATED TO THE CANAL

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*ABSTRACT* Recent papers by Eskinazi, compared to studies made on the Texas and Louisiana coasts 35 to 45 years ago and on the south Atlantic coast 15 years ago, show remarkable similarities of the estuarine fishes of northeastern Brazil and the northern Gulf of Mexico. Forty-five of 48 families of the two areas are in common and about 35% of the species are in common. On the west coast even greater correspondence might be expected between fishes of Peru and southern California, were it not for the restriction of tropical fishes by the Humboldt and California currents.

When the lithospheric plate under North America pulled away from Pangaea, strong swimmers and pelagic fishes maintained connections. Thus, the marine fishes have had strong connections for the last 70 million years. Further, the Pacific and Atlantic faunas were connected until the mid-Pliocene when Isthmus America became continuous about 5.7 million years ago.

Marine euryhaline fishes are much more abundant than their freshwater counterparts. Thus large numbers of marine fishes are found in the fresh waters of Panama. One hundred thirty-seven (137) marine fishes have been found there and 57 species have taken up more or less permanent residence. No freshwater fish have taken up residence in the seas of Panama. The freshwater fishes of Central America came from the south and their movement has been very slow. Isthmus America was a ridged mountainous area with short, small rivers and small basins. The estuaries were small or nonexistent. Thus, one avenue for spread of fishes from fresh water was generally nonexistent. There are 32 river basins in Panama and fish have little access from one to the other. So the river basins have an insular aspect. The Canal runs through only three river basins. There are generally no problems to the passage of freshwater fishes in the Canal but they are stopped by even low salinity and, if back pumping becomes necessary to maintain the lakes used in the operation of the locks, most freshwater fishes will not traverse the Canal. Thus, it may be said that there is little chance of transfer of freshwater fishes from one coast to the other. However, the tarpon has already crossed the isthmus and eight other species, including blennies, gobies and pipefishes, have made the passage according to ichthyological collectors. Actually only four fishes are indubitable crossers. Back pumping will increase the potentiality a great deal but no foreign process of gene flow or heredity other than what is present all over the world today and which was present when the Pacific and Atlantic were connected, is to be expected. Thus a sea level canal would present a new situation but nothing that could be antibiological or deadly.

## COMMINGLING OF FISHES BETWEEN NORTH AND SOUTH AMERICA

The zoogeography of marine and freshwater fishes are quite different affairs, and nowhere is this shown more clearly than in a comparison of the coastal fishes populations of northern South America and southern North America with parallel comparisons of the freshwater fishes of the same regions. The question is touched upon here because it relates to the composition of the fishes of Panama.

## MARINE FISHES

Data concerning the coastal ichthyological fauna of northeastern Brazil which were recently presented by Eskinazi (1972, 1974) show the remarkable resemblance between the genera and species of coastal fishes of northeastern Brazil and the coasts of Louisiana and Texas as described by Gunter (1938a, 1938b, 1941, 1945). The northern Gulf of Mexico lies in the so-called Carolinian Biogeographic Province which also includes the Carolinas, Georgia and northern Florida on the Atlantic. The similarity of the shallow-water fish fauna of the Atlantic and Gulf coasts of this province is now well known. Possibly the best listing of the Atlantic ichthyofauna of this region for comparative purposes is that of Anderson and Gehringer (1965), although it concerns the Cape Canaveral area which is at about the southern border of the Carolinian.

A thorough comparison of shallow-water marine fishes of North and South America would be worthwhile, but that subject is not the concern of this paper. However, a cursory comparison of the species listed by Eskinazi (1974) for northeastern Brazil shows that about 35% of the species along those shores are the same as those off the northern Gulf coast of the United States. Similarly, genera coincide closely and, with regard to Brazilian families, only the Cichlidae, the Erythrinidae and Symbranchidae, freshwater families which are sometimes taken in low-salinity coastal waters of Brazil, are excluded from the northern Gulf. The latter two come to southern Mexico and one comes to Florida and one cichlid has reached Texas fresh waters. Thus 45 of 48 families of the two areas are in common. The strong similarity between the shallow-water marine fishes of the North American east coast, south of Cape Hatteras, and northeastern Brazil is impressive and it may be said that strong ichthyofaunal connections extend from subtropic zone to subtropic zone, inclusively.

On the western coasts of the Americas an even greater correspondence of the marine, shallow-water ichthyofauna from southern California to Peru might be expected because of more equable (low) water temperatures and (high) salinities and a generally more similar environment as a

Manuscript received May 7, 1979; accepted May 14, 1979.

whole, with rocky shores, few estuaries and a narrow shelf. However, Rosenblatt (1967) points out the restriction of the tropics by the Humboldt and California currents on the west coast of the hemisphere.

The geographic reasons for the relations of the coastal fishes of the Americas is worth a short examination. The lithospheric plate under the North American continent began to pull away from the great land mass of Earth before South America did (Raven and Axelrod 1975) and the two continents were well apart (approximately 3,000 kilometers) during most of the Cretaceous Era, for about 100 million years beginning about 150 million years ago. During that period pelagic fishes and strong swimmers maintained connections over the area.

Later, near the end of the Cretaceous Era (cf. Dengo 1973), a series of volcanic and nonvolcanic islands arose which connected the two continents along lines of the future isthmus. This came about some 70 million years ago. Then the shore species of fishes, well separated and differentiated over some 80 million years or so, including the weakly motile bottom-dwellers, spread between the two continents by rafting and the other accidents of biological spreading, which become significant over long periods of time. "Rafting" by fishes would consist of floating along underneath, hiding in crevices or even clinging beneath the "raft" and as such would seem to be more common and successful than for air-breathers.

Thus it may be said that the estuarine fishes of North and South America have had fairly strong connections for approximately 70 million years and possibly more. Furthermore the Pacific and Atlantic faunas of both continents were not separated until the mid-Pliocene when Isthmus America began as an unbroken connection between the two continents (Emiliani et al. 1972). That was about 5.7 million years ago.

Marine fishes of Panama are a section of a vast inshore fauna which extends from subtropic across to subtropic on either side of the equator and on both the Atlantic and Pacific coasts. It is composed of several hundred species, a few of which are no doubt still unknown. These were generally treated by Meek and Hildebrand (1923–28), who listed 757 species. Details of the history of the study of the fishes of Panama have been given by Loftin (1965).

Actually, the chief interest here is in the euryhaline marine fishes, those which are capable of withstanding fresh water. There are not a great many euryhaline species in the strict terms defined by Gunter (1942, 1956), but there are a great many species which tolerate some admixture of fresh water and sea water. Gunter defined a fully euryhaline species of fish as one which has been recorded in both pure fresh water and pure sea water by competent observers. In comparison the partially euryhaline fishes which tolerate mixtures of fresh water and sea water enter from both fresh water and the ocean. However, Gunter pointed out that the marine invaders are much more numerous. In fact the estuarine fauna is predominantly of marine origin all over the whole world.

Miller (1966) lists 137 species of marine fishes which are to be found in the fresh waters or almost fresh waters of Panama, and he states that in the whole of Isthmus America approximately 57 species, or one-third of the marine invaders, have taken up more or less permanent residence in fresh water.

With regard to "pure fresh water," all water from land and even rain water contains some mineral salts. The only boundary between sea water and fresh water which is objective and chemically determinable, is at the concentration where the ratio of the chloride ion to the other ions changes from that of sea water to that of fresh water (Price and Gunter 1964). On coasts with drainage over silicate rocks and sediments the water is "soft" and the ratio change takes place at near 0.18‰. On coasts where the drainage is over carbonate rocks and the fresh water is "hard" the salinity at the change point to fresh water may be near 0.6‰ saline or higher than oligohaline sea water* of other areas.

## FRESHWATER FISHES

No freshwater fishes have taken up residence in the seas of Panama so far as the records show, and as the obverse side of the coin there is a group of freshwater fishes over the world which are extremely reluctant to enter salt water and are never found there (Myers 1938). Myers called them Primary freshwater fishes. A second group, which is made up of those species that occasionally are found in low-salinity waters and sometimes even higher, he called Secondary freshwater fishes. A third group, which may traverse the whole salinity gradient for various reasons, are called Peripheral freshwater fishes. They were originally named by Nichols (1928) who recognized that most of them were of marine affinity. These terms have been adopted by recent students of ichthyogeography (cf. Loftin 1965; Miller 1966).

Isthmus America, as a mid-Pliocene uplift, ranged from Tehuantepec, Mexico, to and including the coastal plain of Colombia, so that the southern part formed a little cap of northern South America. After this connection took place the freshwater fishes and other animals from both continents began to move up and down the isthmus. Older zoogeographers held that most fauna moved from north to south, but as Myers (1938) pointed out, "There is not a scrap of factual evidence . . . on which to postulate a North American origin of the present South American fresh water fishes."

Myers (1938) goes on to say that one characin and one cichlid of the South American fishes have reached Texas. Of the six families of common North American fishes, the

*Some purists would use "salt water" only for artificial brine mixtures and reserve "sea water" only for the oceans. However, there are too many "Old Salts" who have used "salt water" for sea water, or even for the sea itself, for such a change to come now.

four main ones (perches, darters, sunfishes and minnows) have not penetrated Isthmus America and only two suckers and one North American catfish are found below Tehuantepec. The Poeciliidae may be autochthonous to Isthmus America and specifically to the Yucatan land mass (Myers 1938; Miller 1966).

The freshwater fishes of Panama were first extensively studied by Meek and Hildebrand (1916). They listed 94 species of Primary and Secondary freshwater fishes and marine recent invaders. Meek and Hildebrand (1916, p. 233) stated that "the fish fauna of Panama is essentially that of South America and most of the forms seem to have entered from that direction."

Myers (1938, p. 343) has pointed out that "throughout the world the migrations of fresh-water fishes over extensive continental areas have been excessively slower than those of almost any creature that can creep, crawl, walk or fly, however closely that creature may have been bound by its ecological tolerance." And he stated that this is nowhere better illustrated than in Isthmus America.

If the ancestors of the characin and cichlid fishes now found in Texas and New Mexico left South America soon after the isthmus formed, they traveled at a rate of 1 mile in 475 years, 11.10 feet in a year or 0.365 inch (0.9266 cm) per day. This assumes a distance of 3,000 miles and a time span of 5.7 million years. Even if they started only a million years ago the speed of travel has been quite slow.

The reasons for this slow spread of the freshwater fishes are obvious. Isthmus America is mostly a ridged, mountainous strip of land with steep profiles and mostly short, small rivers. The river basins are small. In turn the estuaries are small and virtually nonexistent, especially in the dry season. Bealer (1947) made the statement that in Panama, 475 streams empty directly into the oceans. For that reason the abundant characins and neotropical catfishes in Panama, "a vanguard from the south of the great Amazonian fauna," (Miller 1966) cannot work their way along the sea shores. Even most Secondary fishes are precluded by full sea water and euryhaline groups, such as the Cyprinodontes, are shelter seekers and they do not roam the open beaches far from river mouths and estuaries. Gunter (1945) found only three on the sea beach among 9,010 specimens of six euryhaline species of cyprinodontoids in Texas waters, and these were near the passes to inside waters. Simpson and Gunter (1956), in a study of Texas coastal cyprinodontoids, set up no stations on the open sea beach because experience had shown that it was no place to catch these fishes. Gunter (1957) reported one *Cyprinodon variegatus* and 12 *Fundulus similis* on open beaches among 10,633 other fishes. A few yards away at nearby stations in the passes 584 of the two species were caught.

The numerous small river basins of Panama are well separated by steep ridges. There are 32 of these. In general the gradient is steep and the rivers are short. The Rio Bayano, the largest, is less than 100 miles in extent and many rivers are less than 10 miles long. The average length seems to be about 30 miles. During the dry season many of the smaller streams almost go dry, while in the rainy season they become torrents, and rises in height of 20 feet in an hour's time sometimes take place. These accounts are taken from Meek and Hildebrand (1916) and Loftin (1965), who have been chief ichthyological explorers.

According to Loftin (1965, p. 8), "Panama's system of drainages may be summed up as follows: a large number of short, steep isolated streams with small watersheds, which course rather directly down from the mountains to empty separately into the sea. This feature may be the single most important limiting factor in the dispersal of freshwater fishes in Panama."

The 32 basins in the 29,000-square-mile area average about 906 square miles in extent. The dividing spine generally runs closest to the Atlantic, except near the Canal, and the Chagres River Basin of the Atlantic side is the largest, but one of the lowest in average altitude. Half of the area of the country is above 1,000 feet in altitude with some peaks of 11,000 feet.

These basins are almost as isolated as so many tropical islands at sea, and they have both a higher percentage of marine fishes in their streams and a rather sparse fauna withal. The Panamanian river basins have an insular aspect.

The Canal connects or runs through only three river basins, the Chagres on the Atlantic and the two small basins between the Rio La Capira and Rio Bayano on the Pacific. Only the Chagres connects with the Canal and fish going from one basin to the other would have to go by way of the oceans, which is highly improbable, due to the reluctance of Primary fishes to enter even oligohaline salt water. In any case, no such instance has been noted. Even so, such a case would have probably caused less disturbance than the introduction of the Peacock *Cichlasoma* from Colombia into Gatún Lake did. The lake fishes have not been studied per se, but they are remnants of the riverine ichthyofauna of the Chagres River reported by Meek and Hildebrand (1916) and corroborated by Loftin (1965), species by species. Insofar as there were no natural lakes in all of Panama until the Canal was dug, it would seem that these fishes have been under some stress in the lacustrine environment. The Peacock cichlid is a predator on the other fishes and is now bringing other pressures. It grows to a large size, 20 to 30 pounds, takes the hook avidly one-by-one from a school and is a fine food fish. However, these attributes to not arouse great enthusiasm among Latin Americans.

In any case, it maybe assumed that there will be no passageway problems with freshwater fishes. Hildebrand (1939) said the freshwater fishes seemed to avoid the Canal, but, so far as his data went, this applied to the locks themselves and not the cut or the channel through the lake. This means that these fishes avoid salt water even in its dilute concentrations.

### THE PANAMA CANAL AS RELATED TO FISHES

The Canal runs from Limón Bay on the Caribbean Sea at Cristobal on the northern side to Balboa on Panama Bay of the Pacific Ocean. The course is almost due south for 6.5 miles to Gatún Lock which lifts ships 85 feet up in three stages to Gatún Lake. This lake was formed by damming the Chagres River and covers 164 square miles with depths up to 85 feet. The southward course of the channel continues on in the lake for another 5 miles and then goes directly east. From that point on, there are over 600 cumulative degrees of turns before it reaches the southern terminal of the Bay of Panama, but all are generally southeast. From Gatún, the channel goes through Gaillard Cut to Pedro Miguel Lock, which lowers the ships 31 feet to Miraflores Lake. One mile farther on are the Miraflores Locks, which lower ships 54 feet back to sea level.

The Canal channel is 50 miles long from ocean to ocean. The isthmus is 40.27 miles wide at this point. There are six pairs of locks all 1,000 feet long and 110 feet wide, with walls of 81 and 82 feet high. It takes 7 hours for a ship to pass through.

A ship coming through from the north travels through salt water from Limón Bay to the lock at Gatún Lake where it is raised into fresh water. From there through Gatún Lake, Gaillard Cut and the Pedro Miguel Locks, the ship is in fresh water. In Miraflores Lake, the water is lightly brackish from the Miraflores Locks when the traffic is heavy. In summary, a ship or fish following the same path would travel through 6 or 7 miles of sea and brackish water to Gatún Lake, 37 miles of fresh water through the lake, 2 miles of slightly brackish water in Miraflores Lake and 4 miles of brackish water to sea water at Balboa.

There is no physical barrier to the crossing of the isthmus by a fish, as Hildebrand (1937) has stated. In this connection one should refer to Corps of Engineers reports (1956) and Hall (1956) concerning the locking of mullet (*Mugil cephalus*) from the St. Lucie Canal into the St. Lucie River when they were coming out of Lake Okeechobee, Florida. The Corps of Engineers found that it was much simpler to do this than to let the fish stack up and finally die in large masses at the locks while waiting to get back to sea.

Hildebrand (1939) presented a table from data collected over an unknown number of years by Panama Canal officials, which shows that the salinities at the "Inner Harbor" at both ends of the Canal ranged from 16.0 to 20.0 ‰ saline. In Miraflores Lake it was 0.1 to 3.0‰ and in Gatún Lake it was 0.005 to 0.02‰ (5 to 20 parts per million) or very soft fresh water.

Menzies (1968) towed animals through the Canal and reported a salinity of 25.5‰ in one of the Miraflores Locks, 1.0 in Miraflores Lake, 0.0 in Pedro Miguel Lock and Gatún Lake and 23.5 in one Gatún Lock. Neither time, place, method of salinity determination or depth was given by Menzies.

Abele (1972) found the salinity from top to bottom of the Pedro Miguel Locks to be 0.0 to 0.4‰, with an accuracy of 0.5‰.

Jones and Dawson (1973) took salinities and temperatures at 2-meter intervals from top to bottom at 19 to 22 stations from the Bay of Panama to Limón Bay April 13–May 1, and November 6–15, 1972, at the end of the dry and wet seasons, respectively.

Those authors found that in the locks the water was very homogenous from top to bottom. At the end of the dry season the salinities were near 30.0‰ in the lower Miraflores Locks, 4.0 to 6.0 in the upper and 1.0 to fresh from Miraflores Lake to Middle Gatún Lock. In the lowest lock, Gatún Lock, the highest salinity was 15.0‰. At the end of the dry season Miraflores Lake and the Middle Gatún Lock were salty, while the intervening areas were fresh.

Essentially these reports all agree that from Pedro Miguel Lock to upper Gatún Lock, inclusive, the water is fresh even in the dry season.

### THE CANAL AS A PASSAGEWAY FOR FISHES

Hildebrand (1937) showed that the euryhaline tarpon *Megalops atlanticus* (Valenciennes) had crossed the Canal to the Pacific and they are still reported there from time to time, but ichthyologists fail to catch them in their infinitely miniscule collections and doubt that they have established breeding populations there (Bayer et al. 1970; McCosker and Dawson 1975). In fact it would be quite unexpected for this warm-water, estuarine-loving species to expand quickly along the shores of Pacific America. Recent sports fishing reports with pictures show the fish to be now 150 miles from Balboa.

In addition to the tarpon, McCosker and Dawson (1975) list the following fishes as having crossed the isthmus by way of the Canal:

#### *Atlantic to the Pacific*

*Oostethus lineatus* (Valenciennes). This is a completely euryhaline pipefish and breeds in both fresh and salt water as does *Syngnathus scovelli* on the United States Gulf coast (Whatley 1962).

*Lophogobius cyprinoides* (Pallas). This fish has been found in the Third Lock Lake but a significant meristic difference between this and the Atlantic populations has been reported. However, there is no proof that it has reached the Pacific.

*Barbulifer ceuthoecus* (Jordan and Gilbert). This species was collected in Panama Bay but it is said to not be euryhaline and may have "crossed" in water ballast.

*Lupinoblennius dispar* Herre. Found only in Miraflores Lock, not in the Pacific.

*Hypleurochilus aequipinnis* (Günther). A breeding population was found in Miraflores Lock, but is was not taken in the Pacific.

**Pacific to Atlantic**

*Gnathonodon speciosus* (Forsskål). This fish has been taken from the lower Gatún Lock but has never been seen in the Atlantic.

*Ombranchus punctatus* (Valenciennes). This Indo-Pacific goby has been found in Limón Bay. It is also found in Trinidad and Venezuela. Possibly it has been there for ages.

*Gobiosoma nudum* (Meek and Hildebrand). This goby was reported from Galeta Reef (Atlantic) one time.

Of the eight above species listed by McCosker and Dawson (1975) under the headings, "Marine Fish Migrants, Atlantic to Pacific," and "Pacific to Atlantic," there is one large fish, a carangid; one pipefish; three blennies and three gobies. Of these the pipefish *Oostethus lineatus* and the gobies *Ombranchus punctatus, Gobiosoma nudum* and *Barbulifer ceuthoecus*, have been found in the other ocean. The pipefish seems to be an authentic migrant to the Pacific. The goby *Ombranchus punctatus* could have scarcely spread from Limón Bay to Trinidad and Venezuela since the Canal was opened and the most reasonable conclusion is that it has been a resident of both coasts for a long time. The goby *Barbulifer ceuthoecus* is admittedly stenohaline and came in ballast. *Gobiosoma nudum* seems to be an actual migrant across the isthmus. Thus the tarpon, the pipefish and one goby are indubitable migrants across the isthmus by way of the Canal. At this rate it will take the 66 euryhaline fishes of Panama waters, according to Miller's (1966) count, a matter of 1,950 years to cross the Canal as it is now constituted.

McCosker and Dawson (1975) accept all putative canal crossers as crossers. For that reason they agree, although reluctantly it seems, with the conclusions of Bayer et al. (1970) that "there is no evidence to suggest any exchange of reef fishes through the present canal" and "current exchanges involve estuarine fishes, primarily gobies and fishes that can live among the fouling organisms on the hulls of ships." However, the collections by these workers were made so far out on the Continental Shelf that the collections shed no light on the question of migration across the isthmus; and if the conclusions are correct, they derive from the prescience of experienced biologists and not from any particular data presented. However, Hildebrand adduced information somewhat contrary to those conclusions.

Hildebrand (1937) previously gave evidence that the tarpon had crossed the isthmus and he gave more in 1939. He also said that *Anchovia parva* Meek and Hildebrand had crossed the freshwater barrier to the lower Miraflores Lock on the Pacific side. Remarkably enough he also reported the spotted jewfish, *Promicrops itaiara* (Lichtenstein), of the Atlantic from the lower Miraflores Lock. The fish weighed 47 pounds. These last two species are certainly putative crossers.

Significantly, Hildebrand's records and pictures show that several species and families of large fishes enter the locks, for example, the carangids or jacks, snooks, seabasses, groupers, snappers, grunts and sciaenids. These are not small blennies or gobies skulking in the fouling mats. Large fish can go through if they can pass the freshwater barrier. Gunter (1942) listed nine fishes from Panama that were fully euryhaline. On that list *Oostethus lineatus* was listed as only a "probable euryhaline." Meek and Hildebrand (1923) reported it as breeding in the fresh water of Gatún Lake.

In all, there are four fishes that have made indubitable crossings of the present Canal and gotten free of man's works. Only one, the tarpon, is a large fish. The other three are the pipefish *Oostethus lineatus*; a noneuryhaline goby, *Barbulifer ceuthoecus*, which evidently was carried by ship; and *Gobiosoma nudum*, the naked goby.

Additionally there are putatives, probables and possibles, numbering some 15 or so fishes, if circumtropical species are included, such as *Caranx hippos, Mugil cephalus* and *M. curema.* If such species do cross it would be difficult to prove unless they were tagged. This means that no effect of their crossing can be detected, even though they have been separated at least 5 million years and the Pacific jack was considered to be a different fish, *Caranx caninus*, until recently.

It is significant that both Hildebrand (1939) and McCosker and Dawson (1975) thought that they found evidences of hybridization in the gobies taken within the Canal.

The projected use of the Canal shows that in the year 2000 and thereabout the Canal traffic will use up in about a month's time the 22 billion cubic feet of water held in Gatún Lake as a reserve. Back pumping has been suggested as a way out of this dilemna and it will no doubt suffice. The objection has been raised that this action will increase the salinity to such an extent that it will cause Gatún Lake and the Canal to become a greatly used thoroughfare for the fishes and even the sea snakes from the Pacific side. The comments especially from various ichthyologists say that this action would be "unwise," "irresponsible," "indefensible," "dangerous," etc. Such terms are not science and in fact are those that can be heard in adversary court trials any day. One report has even suggested that there will be some sort of change in the germ plasm so that the invaders will exert some sort of overwhelming dominance over the indigenous biota. We may wonder on this basis what evolutionary horrors were caused by freeflowing and commingling oceans in the days before the isthmus became a complete barrier.

With regard to the salinity and what will happen when and if Gatún Lake attains a salinity of 5.0‰, which the engineers say is the most likely equilibrium to be attained by back pumping, there is not a great deal of information available. However, Gunter (1945) found that at the salinity range of between 0.0 and 5.0‰ in Texas waters, the number of species of fishes was about one-half of those recorded at salinities of 30.0‰ and above. Most of these were predominantly small and young specimens. Thus,

Gatún Lake might be expected to assume characteristics of a very low-salinity estuary so far as the marine fishes are concerned. It would also retain a good bit of its freshwater fauna while losing some of it.

Myers (1949) was troubled about his category of Primary fishes because some of them have been found capable of tolerating high salinity, if acclimated gradually under experimental conditions. The salinity of a freshwater fish's blood is equal approximately to one-third sea water and at any salinity below 12.0‰ it maintains the hyperosmotic relationship of a freshwater fish to the salinity of the water. Some freshwater fishes live in quite highly saline lakes in the United States and hopefully the fishes of Gatún Lake would not be greatly disturbed by the slow increase of salinity to 5.0‰.

The efficiency of the Canal as a passageway for fishes between the oceans would be indubitably increased by back pumping. In terms of proportions of the salinity change, some 30 species of fishes would be expected to make the crossing. Presumably these would be the snooks, jacks, mullets, snappers, gobies and other fishes now known to be euryhaline and semi-euryhaline in this region. As a result, there would be a change in competition in habitat niches, in interbreeding, in food chains and some change in gene flow, population genetics and general competition.

In summary, the same old evolutionary panorama that goes on at all times in all oceans would be changed somewhat by back pumping, but not in any way that could be called unnatural. These changes would be hard to detect and hard to follow except for the presence of different species in an area where they were not known before. There is no reason to expect that these biological processes will fail to take place, or will change in any way to make them more or less strenuous, more or less wasteful of basic energy processes, or change in any way which can be objectively described as harmful, unless perhaps someone prefers one goby to another. Even so, these people can scarcely suffer over the preferred one's demise over a period of 500 to 1,000 years, which would probably be the time required. The same general situation will hold true for a sea level canal.

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Gulf Research Reports

Volume 6 | Issue 3

January 1979

# A Filamentous Bacterium on the Brine Shrimp and Its Control

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DOI: 10.18785/grr.0603.08

*Gulf Research Reports,* Vol. 6, No. 3, 275–281, 1979.

# A FILAMENTOUS BACTERIUM ON THE BRINE SHRIMP AND ITS CONTROL[1]

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*ABSTRACT* A strain of a colorless, filamentous bacterium (tentatively identified as *Leucothrix mucor*) heavily infests the brine shrimp, *Artemia salina.* Its ultrastructure, unlike that of some other strains, does not reveal a distinct middle layer between its outer cell wall layer and cytoplasmic membrane, irregular blebs extending from the cell layers, or an external sheath. An entire infestation, represented as a mat of the bacterium with associated debris and microorganisms, sloughs from the shrimp when exposed to a variety of treatments. Primarily because most effective treatments are toxic to the shrimp, 100 ppm terramycin provides the treatment of choice.

## INTRODUCTION

A bacterium, tentatively identified as a strain of *Leucothrix mucor,* infested 100% of the adult brine shrimp, *Artemia salina,* in a 200-liter intensive culture tank. These heavily infested shrimp died at a faster rate than the stock could be replaced by maturing individuals. Death, however, did not appear to occur rapidly upon infestation. Because of the vulnerability of the shrimp to the bacterium, the known pathogenic effect of *L. mucor* on many crustacean larvae and eggs confined in rearing facilities (e.g., Nilson et al. 1975, Lightner 1975), and the potential to contaminate larval crustaceans by feeding them brine shrimp, we tested a variety of treatments on infested individuals. Also, because of the large number of poorly characterized strains of *L. mucor,* we present some morphological data on the form we encountered.

## MATERIALS AND METHODS

Infested *Artemia salina* were obtained from the Oyster Biology Section of the Gulf Coast Research Laboratory. Brine shrimp eggs, presumably uninfested, came from San Francisco Bay ponds and the hatched shrimp were maintained in salinities of 45 to 50 parts per thousand (ppt) at 23 to 25°C with whole wheat flour; adults averaged 11 mm in total length.

In order to identify the bacterium, we observed it with a Nomarski differential interference contrast and an electron microscope, studied it histologically, and cultured it using the methods of Pringsheim (1957). A few heavily infested brine shrimp were embedded in paraffin and sectioned at 6 to 7 $\mu$m, and the sections were stained using Harris' hematoxylin and eosin stain, Bennhold's method for amyloid, McManus' method for glycogen (PAS), and alcian blue method for mucosubstances (Luna 1968). Additional material was fixed in 3% glutaraldehyde, post-fixed in osmium tetroxide, embedded in Spurr's embedding medium, sectioned on an LKB ultratome, stained with uranyl acetate and lead citrate, and photographed with a Siemens Elmiskop 1A electron microscope.

Infested shrimp in groups of about 15 individuals were placed in glass bowls each containing 70 ml of artificial seawater (50 ppt, Rila Marine Mix) at 24±1°C. Diseased shrimp were exposed to the various chemicals listed in Table 1. All tests were conducted in duplicate or triplicate, usually for periods of time commonly used for each type of treatment. When treatments lasted 48 hours, saltwater and chemicals were replaced after 24 hours. Experimental hosts were not fed while tested, and we defined cure as the absence of bacterial filaments.

## RESULTS

### *Bacterium*

The colorless, filamentous bacterium attached its PAS- and congo red-positive holdfast to the gills, swimming appendages, antennae, and all other external surfaces of the shrimp's adult and late instar stages. The site of attachment stained purplish-red to purple using McManus' method and predominately blue using the alcian blue method. A loose mesh of bacterial filaments helped trap and support considerable debris and a variety of unidentified microorganisms (Figures 1–4). Rosettes of filaments occurred commonly (Figure 5). Some infested appendages exhibited extensive deterioration, but the histological relationship between the bacterium and those lesions was not critically examined. Most attached filaments did not appear to penetrate deeply into the cuticle, and we never observed filaments extending through the cuticle or within a host.

Filaments varied in appearance. Most typically contained refractive granules (Figure 4); however, many filaments had few or no granulated segments. We did not analyze the chemical composition of these granules. Widths of 50 typical

[1]This study was conducted in cooperation with the U.S. Department of Commerce, NOAA, National Marine Fisheries Service, under PL 88–309, Project Nos. 2–262–R and 2–325–R.

Manuscript received July 27, 1979; accepted August 13, 1979.

TABLE 1.

**Treatments tested for controlling infestations of *Leucothrix mucor* on adult brine shrimp.**

| Treatment | Number of shrimp | Number of replicates | Concentration[1] | Exposure-period in hours | Average percentage cured ± SE | Average percentage died ± SE |
|---|---|---|---|---|---|---|
| Control | 152 | 9 | — | 48 | 25.5 ± 2.5 | 34.2 ± 6.9 |
| Formalin | 46 | 3 | 40 ppm | 12 | 58.7 ± 5.2 | 21.7 ± 7.3 |
| Potassium permanganate | 45 | 3 | 10 ppm | 1 | 44.4 ± 4.7 | 20.0 ± 3.1 |
| Nitrofurazone[2] | 46 | 3 | 100 ppm | 6 | 47.8 ± 3.8 | 10.8 ± 2.8 |
| Cutrine[3] | 45 | 3 | 100 ppm | 4 | 60.8 ± 3.2 | 15.2 ± 1.4 |
| Cutrine | 45 | 3 | 100 ppm | 48 | 28.8 ± 6.5 | 53.3 ± 3.9 |
| Cutrine | 45 | 3 | 0.5 ppm | 4 | 51.1 ± 1.8 | 20.0 ± 3.1 |
| Cutrine | 47 | 3 | 0.5 ppm | 48 | 48.2 ± 7.3 | 48.9 ± 8.8 |
| Terramycin[4] | 78 | 5 | 10 ppm | 48 | 37.1 ± 5.5 | 38.4 ± 3.1 |
| Terramycin | 77 | 5 | 50 ppm | 48 | 45.4 ± 7.2 | 36.3 ± 6.7 |
| Terramycin | 74 | 5 | 100 ppm | 48 | 67.5 ± 8.1 | 25.6 ± 4.6 |
| Terramycin | 84 | 5 | 200 ppm | 48 | 51.1 ± 2.2 | 21.4 ± 6.1 |
| Terramycin | 16 | 1 | 200 ppm | 1 | 43.8 | 12.5 |
| Salinity reduction[5] | 47 | 3 | 10 ppt | 48 | 72.3 ± 9.3 | 19.1 ± 8.8 |
| Freshwater | 15 | 1 | 0 ppt | 1 | 40.0 | 33.3 |

[1] Based on commercial preparations and not active ingredients
[2] 5-nitro-2-furaldehyde semicarbazone
[3] Copper sulfate + triethanolamine and other additives
[4] 4-(Dimethylamino)-1,4,4a,5,5a,6,11,12a-octahydro-3,5,6,10,12,12a-hexahydroxy-6-methyl-1,11-dioxo-2-nephthacenecarboxamide
[5] Produced with Rila Marine Mix

filaments from three shrimp ranged between 1 and 2 μm. Cells near the base of the filaments averaged 2.3 μm (1.0 to 2.9 μm) long by 1.8 μm (1.5 to 2.0 μm) wide, those near the middle were 1.6 by 1.6 μm, and those near the apex, 2.2 by 1.0 μm. Twenty nongranulated cells near the middle of a filament averaged 2.4 by 1.3 μm.

Examination of the filament's ultrastructure revealed fibrillar nuclear material, storage granules, and ribosomes dispersed in the cytoplasmic matrix. All those features (Figures 6–11) are considered typical components of *L. mucor* in its broad sense, except for an aspect presented in Figure 8 and mentioned below. The outer wall layer and the cytoplasmic membrane were both simple and smooth. Each was about 11 nm wide with the total wall about 45 to 55 nm wide.

Some filaments appear similar except the cells obtain a length as long as ten times the width. Figure 8 illustrates the variation in length between adjacent cells of these filaments. The long cell length is not typical of *L. mucor*, and the organism probably represents a strain or species distinct from the dominant organism of our study.

The cuticle at the site where *L. mucor* attached (Figure 7) was altered and notably rougher than the smooth adjacent cuticle. No significant underlying cellular damage was apparent, even though slight penetration of the holdfast occurred within the cuticle.

The second cell in the middle filament of the rosette in Figure 7 represents one of several similar examples observed; it differed from the others shown by having more granules and a large, central, irregularly shaped, compact structure. The cell is possibly a reproductive cell; however, we do not discount the possibility of a normal cell undergoing degeneration.

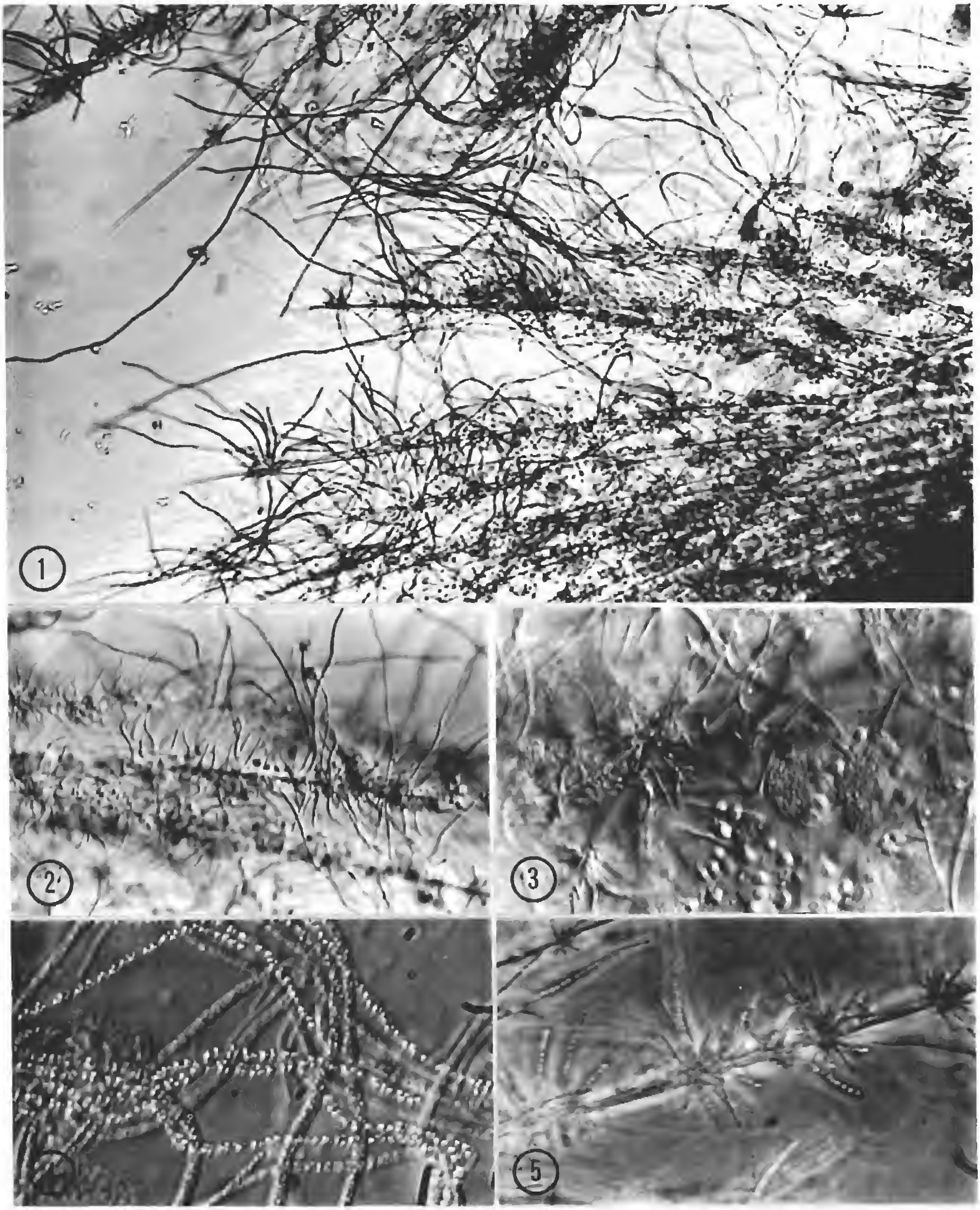
Nauplii had no conspicuous infestations, whereas juveniles at about the sixth instar, the stage when the rate of molting frequency decreases, possessed numerous short filaments, both isolated and in rosettes.

A moderately heavy infestation was conspicuous when comparing an infested host with a noninfested shrimp (Figures 9–10). The entire bacterial mass sloughed from treated individuals (Figure 11).

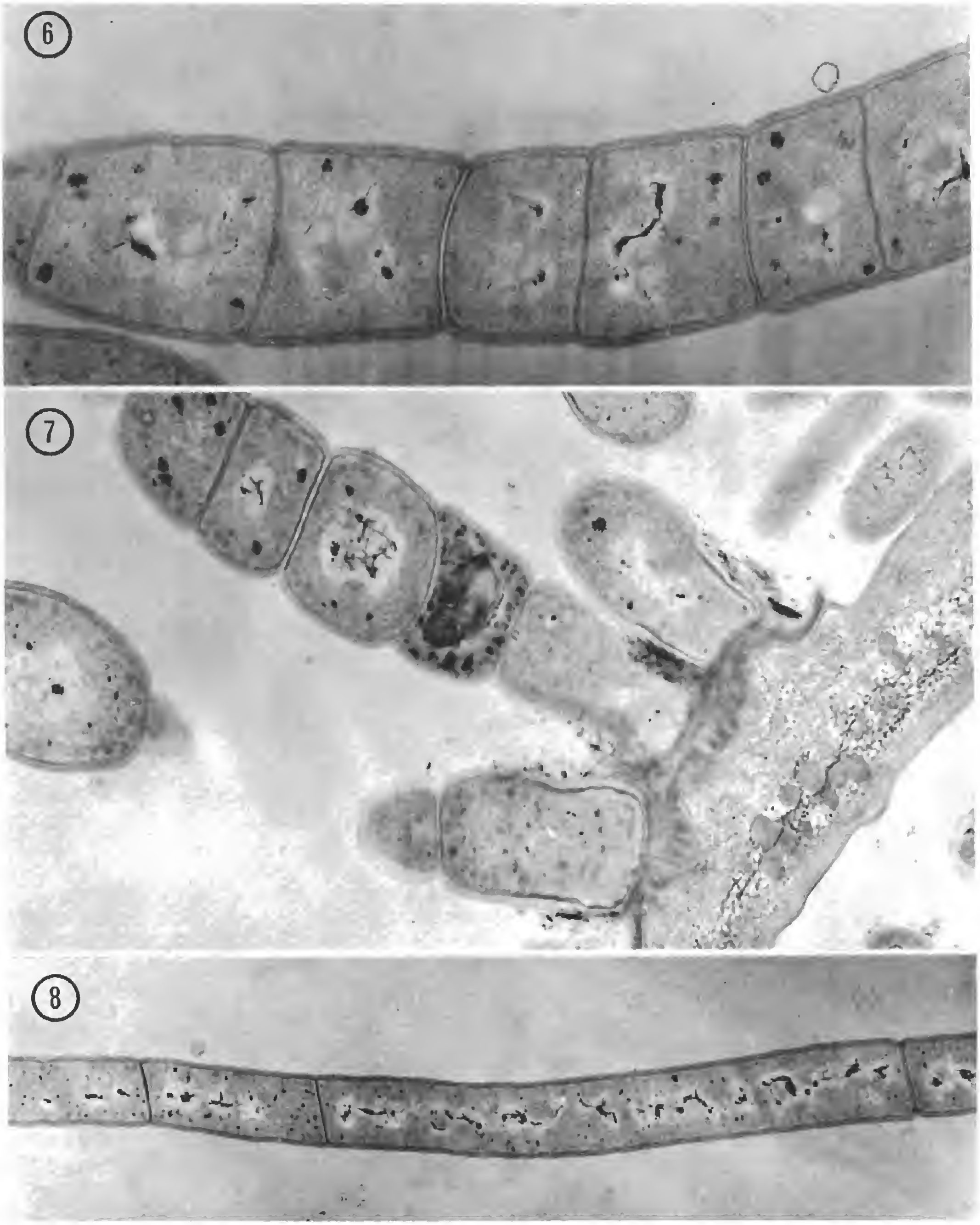
In a single attempt to culture our material, no more than eight cells developed in a chain. Numerous spherical cells, presumably gonidia, glided about on our "slide cultures." Filaments could not be demonstrated from liquid media when kept stationary or shaken or from a streaked agar plate.

### *Treatment*

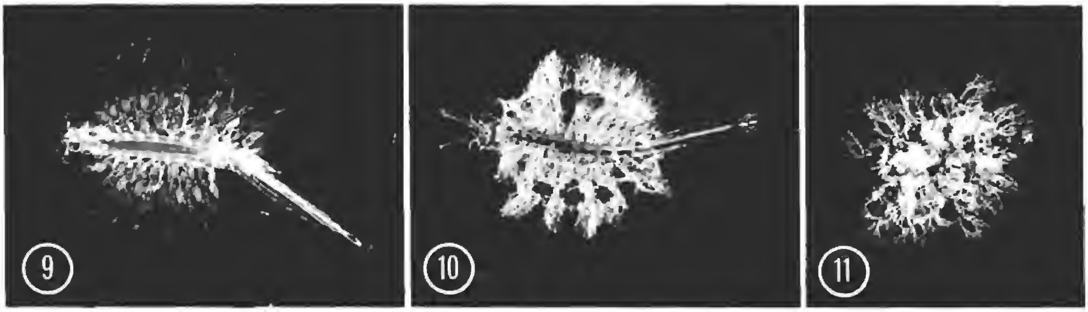
The average percentage per replicate of adult brine shrimp having sloughed bacterial mats and remaining free of *L. mucor* after exposure to a variety of treatments is listed in Table 1. Moderate variations in results for each concentration occurred among replicates. All treatments indicated some success for cure, but for reasons presented in the discussion




Figures 1–5. *Leucothrix mucor* on brine shrimp. (1) Moderate infestation showing abundant debris. (2) Close-up of setae showing attached bacterial colonies. (3) Close-up of debris and microorganisms. (4) High-power view of filaments showing granules. (5) Rosettes on brine shrimp seta.




Figures 6–8. Electron micrographs of filamentous organisms on brine shrimp. (6) Typical cells comprising a filament of *Leucothrix mucor*, x 32,800. (7) Holdfast attachment site for a rosette of *Leucothrix mucor*, x 29,300. Note assumed reproductive cell situated as second cell in middle filament. (8) Filament with some elongated cells, probably not *Leucothrix mucor*, x 16,100.




**Figures 9–11. Photomicrographs of control shrimp and infestation of *Leucothrix mucor*. (9) Noninfested brine shrimp. (10) Brine shrimp moderately infested. (11) Sloughed mat and associated debris.**

and in Table 1, treatment with 100 ppm terramycin seemed most practical.

## DISCUSSION

*Leucothrix mucor* comprises a variety of over 30 strains (Raj 1977). Characterizations of these strains based on the combination of morphological features, biochemical assessments, and culturing ability are known for only a few. Because identification of our material is not positive and variations among strains are considerable, we tentatively consider our strain one of *L. mucor.*

Some strains of *L. mucor* differ in many respects from the one we report. Ours from the shrimp fits no clearly defined assemblage of characteristics. It has no sheath-like layer around the cell wall such as that reported by Anderson and Heffernan (1965), but neither do most strains. Brock and Conti (1969) showed irregularities and bleb-like extensions from the cell layers and a well-formed, thin, single-membrane, or middle layer (peptidoglycan), between the inner and outer double membranes, whereas the present form has relatively smooth membranes and no distinct middle layer. Abundant rosettes, such as those present on the brine shrimp, are not thought to be typical in rich nutritional regimes (Raj 1977). Steenbergen (San Diego State University, personal communication) has shown that a strain from the shrimp *Penaeus californiensis* has a uniquely different guanine-plus-cytosine ratio of deoxyribonucleic acid along with a lack of antigenic similarity when compared to other isolates. Consequently, that strain may not be *L. mucor.* The electrophoretic mobilities of enzymes were not studied in our material, but Kelly and Brock (1969) have shown significant differences in mobilities of two dehydrogenases from different strains. Strains also differ in their tolerance to salinity.

The status of the one or more species of *Thiothrix*, which closely resemble *L. mucor*, also remains uncertain because these anaerobic forms containing sulfur granules have not been consistently cultured. The composition of granules in our aerobic material was not analyzed, but their presence was inconsistent. Some filaments had them and others did not; moreover, a filament occasionally consisted of cells both with and without granules. Filaments from moribund shrimp, following three days of a gradual reduction in salinity, also possessed cells with and without granules. In any event, the presence and absence of granules did not provide evidence indicating the existence of two separate species or strains.

The holdfast did not spread out over the host's cuticle nor did it penetrate extensively. Couch (1978) suggested that the assumed mucoid substance of this holdfast might coat the gills of penaeid shrimp and block gas diffusion. We found that the cuticle became deformed at the attachment site. The holdfast of a strain of *L. mucor* on the peritrich *Zoothamnium* sp. infesting the gills of penaeid shrimp has been observed by Foster et al. (1978) to penetrate the stalk of the ciliate and to spread out into the extracellular fibrillar matrix. *Leucothrix mucor*, on occasion, probably penetrates several organisms or their products. It entangled the ciliate *Epistylis* sp. on fishes in low-salinity habitats (Overstreet and Howse 1977), but the filamentous organism (0.3 μm wide) within the stalk was definitely not *L. mucor* as implied by those authors (in their Figure 31).

In the natural environment, many crustaceans remain free of infestations by preening themselves. Bauer (1977) showed this by ablating the third maxillipeds of the shrimp *Heptacarpus pictus* so that it could not groom its antennules. The antennules of these test individuals became heavily fouled with *Leucothrix* sp.

*Leucothrix mucor* infests *Artemia salina* and many other crustaceans extensively when the medium is rich with nutrients. Consequently, rearing facilities foster infestations. According to J. A. Quick, Jr. (Dow Chemical Company, personal communication), *L. mucor* infests the shrimp only when the medium is enriched, even though shrimp populations exceed 100 per liter. Consequently, when practicality prevents culturing crustaceans by decreasing the nutrient levels, treating the system with chemicals should be considered. When contaminating rearing facilities, several strains of *L. mucor* can kill animals' hosts. Lightner et al. (1975) postulated that heavy infestations on penaeid shrimps caused

hypoxic conditions for the shrimp which thereby weakened or killed them, especially those shrimp molting or already in low-oxygen conditions.

In all the treatments tested (Table 1), the entire infestation on an individual sloughed as one mat. A mat involving some appendages and setae can be seen in Figure 11. Sloughed mats seemed to remain attached to a complete or partial molt involving the infested regions. Follow-up attempts to acquire mats for ultrastructural analysis of the holdfast and cuticle were unsuccessful. Such an investigation, however, seems desirable because sloughing often occurred within 1 to 2 hours after treatment.

The 2-day treatment with 100 ppm terramycin seemed the most desirable. In fact, introduction of 100 ppm into the culture tank eliminated the organism permanently, suggesting that the drug killed the parasite. The only other reported use of terramycin in controlling *L. mucor* was by Sandifer and Smith (1976) who obtained inconsistent results using 1-hour dips of concentrations up to 30 ppm. Their strain infested reared juveniles of *Macrobrachium rosenbergi* (the Malaysian prawn) in salinities of 12 to 13 ppt. We found an increasing percentage of cured individuals and a decrease in mortality as we increased the dose to 100 ppm. A concentration of 200 ppm produced results similar to those of 100 ppm.

Treatments other than terramycin had a variety of drawbacks. Rapidly decreasing the salinity from 50 to 10 ppt was successful, but the shrimp cannot survive and reproduce in low-salinity conditions for extended periods. Consequently, bacteria in the system would presumably reinfect the shrimp if the salinity were increased or if the shrimp from water with high-salt content were removed, treated, and returned. Moreover, when gradually decreasing the salinity to 10 ppt over 48 hours, only 2 of 17 shrimp sloughed their bacterial mats.

When under stress from many chemicals for time periods of various lengths, the brine shrimp is hardy. For example, specimens could withstand more than 10 minutes of 3% glutaraldehyde or 10% formalin and then live for at least 1 hour if transferred to normal sea water. On the other hand, even low concentrations of certain chemicals caused pathological responses in shrimp. Both potassium permanganate and formalin, used as indicated for treatments, caused shrimp to twirl, a continuous orbital movement from the surface to the bottom of the water column. Most host deaths caused by those compounds occurred during the first day, whereas those recorded in other treatments except Cutrine-plus® occurred gradually. Sandifer and Smith (1976) noted heavy mortality of prawns with $KMNO_4$ for long and short exposures, and Lightner (1977) reported a potential for severe gill damage in penaeid shrimp following a 1-hour treatment of 10 ppm. In our material, we noted blackened gills.

Twirling occurred in all treatments except terramycin, with that behavior most pronounced in high concentrations of cutrine and least pronounced in nitrofurazone. Nitrofurazone appeared to be the second-best treatment, but was tested for 6 hours only and should be investigated further.

The algacide Cutrine-plus (a chelated copper compound), while an effective drug for brine shrimp in a bath for up to 4 hours, caused many mortalities during 48-hour exposures, even at 0.5 ppm of the commercial product. In addition to twirling, those shrimp exposed to Cutrine-plus for less than 4 hours at 100 ppm also rotated in a spiral around their own axes. Lightner and Supplee (1976) also noted a toxic response by the California brown shrimp to that drug. In order for those authors to increase biomass and decrease mortality of that shrimp, they introduced 0.1 ppm Cutrine weekly for a 24-hour period in a flow-through system. A few other treatments have been tested with a variety of success (Lightner 1977, Sindermann 1977).

ACKNOWLEDGMENTS

We thank J. A. Quick, Jr. for allowing us to utilize some of his extensive knowledge on brine shrimp. David W. Cook provided culture media, Roswitha Buxton assisted with the superb electron micrographs and histochemical results, and John Ogle provided technical help.

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Gulf Research Reports

Volume 6 | Issue 3

January 1979

# The Annual Flows of the Mississippi River

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DOI: 10.18785/grr.0603.09

*Gulf Research Reports*, Vol. 6, No. 3, 283–290, 1979.

# THE ANNUAL FLOWS OF THE MISSISSIPPI RIVER

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*ABSTRACT* The Mississippi River drains two thirds of the lower United States plus 13,000 square miles of Canada. When North America was being colonized by Europeans, the river overflowed its banks about once every 3 years and spread onto the floodplain, which today covers 34,600 square miles of the valley. A natural levee formed alongside the river where the silt was dropped when water left the channel; the levee now slopes away from the river at about 7 feet per mile. This high ground was settled first by the white man at New Orleans in 1717. The spring floods barely topped the natural levee and the original town was protected by a ring levee 3 feet high. As more overflow areas were cut off from the river, the levees increased in height to about 40 feet. The hydraulics of the river became better and today more water and silt flows out to sea. About three fourths of the floodplain is closed off from the river, but in 1882 and 1927, the river took that land back, and in 1973 almost 60% of the 22-million-acre area was flooded. Nevertheless, there have been no levee breaks since the Corps of Engineers took over flood control in 1928.

The mean flow of the river since 1900 has been 646,000 cubic feet per second (cfs) moment to moment. The mode, median, quartiles and deciles of annual flows are given, and the measurements of dispersion, the standard deviation and coefficient of variation are given.

The Atchafalaya River distributary has increased considerably at the expense of the Mississippi River since 1858. During the flood year of 1973, the Atchafalaya carried 37% of the total flow. It is estimated that unless it is brought under control, in about 60 years the Atchafalaya will equal the Mississippi.

Flood years are not especially associated and in several cases low flows and flood years are close together.

Measurements of river flows before 1900 are unreliable or absent. Since then, however, careful measurements of the daily flows of both distributaries have been taken by the Corps of Engineers and used to compile mean flows in cfs by years.

The data extend for a series of 79 years. They were furnished to the author by the New Orleans District of the Corps. These data were used for all calculations given here on flows. The lowest flow recorded for the Atchafalaya was 13,300 cfs on September 22, 1925. The lowest flow for the Mississippi was 75,000 cfs on November 4, 1939. The highest for the Atchafalaya was 781,000 cfs at Simmesport on May 12, 1973; the highest for the Mississippi was at Tarbert Landing on February 19, 1937, at 1,977,000 cfs.

Subjectively described floods of 1782, 1828, and 1882 tie in with 1927 and 1973 as 50-year floods. The 1927 and 1973 floods were remarkably similar; the former was the larger. The largest known flow of the river is only 25% less than the maximum which meteorologists say could be generated. Presumably such a flood could be handled without catastrophe.

## INTRODUCTION

The establishment of European civilization in North America may be looked upon as a long march across the continent as the people established settlements, clearings and highways, and undertook utilization of the natural resources. This process can be divided into three large undertakings which resulted in actual change of the physical landscape. The first task was the clearing of the impenetrable eastern forest which was then crossed only by Indian trails. This magnificent area of climax forest was not felled by the lumbermen; instead it was cut and burned piecemeal to make clearings for the settlers. West of the Mississippi River, settlements involved the plowing of the prairie and the killing of the buffalo. These processes brought about destruction of both the tall and short grass prairies. The introduction of livestock and the activities of farming insured the prolonged destruction of the prairies.

Another vast change introduced by the white man has been his attempts to control the preeminent central Mississippi River which drains much of the lower United States and part of Canada. The river and its appurtenances comprise geographic and geological factors. As such, it is difficult to control and, in fact, cannot be controlled except within very definite narrow limits. Thus, unlike the biotic provinces conquered and partially obliterated by man, the Mississippi gives the impression of fighting back at encroachments upon its domain. Obviously, if mankind is to control the river, even to a small extent, we must know as much as possible about it. Herein the writer analyzes to some extent the characteristics of the annual flow. At the end of the present year, 1979, we shall have a time series of only 80 years of adequate data dating from 1900 to consider. Variations in previous flows are considered where they are known.

## BACKGROUND INFORMATION

The Mississippi River watershed is exceeded in area on Earth only by the watersheds of the Amazon and the Congo. It drains two thirds of the lower United States (some

[1] At various times between 1938 and 1979, the writer has been an employee of the Sacramento District and consultant to the New Orleans and Vicksburg districts and various other districts of the Corps of Engineers and to the Office of Chief of Engineers, U.S. Army, Washington.

Manuscript received July 24, 1979; accepted July 26, 1979.

1,244,000 square miles) and about 13,000 square miles of Canada. The average rainfall over this area is about 30 inches and about one fourth of this reaches the sea by way of the river. The economic and historical influences of this great river system have been enormous. Geographical, geological and hydrographical descriptions, and some history of the river have been given by Trowbridge (1930), Elliott (1932), Russell (1936, 1948), Fisk (1944) and Gunter (1952).

The river begins in Minnesota and flows southward within its alluvial plain between the escarpments of its valley. In a few places it touches these escarpments as at the bluffs of Vicksburg and Natchez.

The river has a natural levee all along its floodplain which consists of fine, alluvial soil that forms from sand and silt deposits when the river overflows its banks during high-water periods. Essentially the load is deposited quickly as the current speed falls after it leaves the channel. This levee slopes away from the river, at the rate of about seven feet to a mile, to the low-lying swamps on either side. This natural levee system was the finest land available when the first white man came into the country, and it was better drained than any other land of the area.

High water comes every year between December—January and June—July. A flood ensues when the river overflows its natural levees. The area which is subject to flooding under natural conditions consists of 34,600 square miles or 22.1 million acres south of Cairo, Illinois, including 18,000 square miles of deltaic plain. Floods occur about every three years under natural conditions, but nowadays they are largely restrained by man-made levees.

The fine arable land along the river which remained high and dry after the spring floods had gone down, in contrast to the swampy areas back away from the river, led to extensive settlement up and down the river banks, beginning when New Orleans was first settled in 1717.

The river was the great travel connection from the days of the pirogues and canoes of the Indians and early explorers, to the time of the flatboats and steamboats and today the powerful diesel-motor towboats, with their huge strings of barges, and the ocean-going freighters. The fact that the river was the great avenue of travel and commerce, reinforced the tendency of the Europeans to settle along its banks. The only alternative was for the settlers to go beyond the swamps to the edges of the valley itself, that is to the escarpments, which were sometimes as much as 50 miles away.

The river did not overflow and discommode the settlers every year but rather about once every three years, and even so, the floods were not very high in the beginning, although they filled in the back waters at times and went to the very edges of the valley, being commonly 50 miles wide along the lower river and even 80 miles in the widest place. But the vast areas of swamps lying alongside the river acted as overflow basins for floods and when the white man first came to live along the river, low levees or banquettes, three feet high around the Vieux Carré or Old Square, sufficed to protect the settlement of Nouvelle Orleans.

In brief, it may be said that various situations and conditions constrained the white man to settle in areas which were naturally part of the river's overflow area and which was subject to flooding. Circumstances which were not even recognized and of which the future portent was not foreseen, set the European settler upon the course of opposing and fighting the river rather than trying to live with it. Living with the river would have entailed building human dwellings and other structures on pilings or earthen banks about three feet high. However, it was easier to build a low embankment around the town of New Orleans and this was first completed in 1721. In effect, the colonials built a ring levee. This was a rather innocent beginning, but as settlers moved up and down the river they were forced for their own protection, and later by law, to build levees and the river was cut off more and more from its natural overflow areas. As this took place, the floods and in turn the levees became higher so that now they are up to 40 feet. This situation was aggravated along the lower river by the closure of former distributaries, Bayou Manchac to the east just below Baton Rouge, and both Bayou Plaquemine and Bayou Lafourche lower down on the west bank.

This situation was reviewed and summarized by Gunter (1952, p. 123) in the following words:

> "Levees grew ever higher as the river was cut from its flood basins and so did floods. Today levees at some points are thirty-five feet high. In addition many tributary streams were leveed and they in turn were cut off from their flood basins. Maps of the present system show a bewildering tracery of leeves, quite difficult to describe in detail, which however is unnecessary for our purposes. It is sufficient to say that the total levee system was around 991 miles long in 1880 and 2,130 miles long in 1935.
>
> Up to 1885 the effects of levees were not so great as they have become since. According to Elliott (1932, p. 83) the flood of 1882 may be taken as typical of a major flood prior to extensive levee construction. 'Comparison of succeeding flood crests with this flood gives a definite indication of the increase in flood heights.' He gave figures taken at the Carrollton (New Orleans) gauge showing that the crest was at 14.95 feet in 1882, 16 feet in 1890 and 21 feet in 1912. The Red River Landing gauge registered 48.50 feet in 1882, 53.20 feet in 1912 and 57.45 feet in 1927. The greatest flood of all was in 1927 when numerous crevasses modified flood heights on the lower river, making them useless for comparison. At the Cairo, Illinois gauge the 1927 high water crest was at 56.4 feet. The highest previous crest was at 54.69 feet in 1913. At the time of the 1912 flood the gauge stood at 54.0 feet.
>
> In summary, levee construction started in 1717, 235 years ago, at New Orleans and was a gradual

process up until about 1880. From that time the rate was accelerated, until the nineteen-thirties when the whole system was greatly extended and more or less stabilized, following the disastrous flood of 1927. Flood heights became higher as the levee system increased."

Viosca (1927) discussed the developments that would have come about along the river if the white man had not elected to fight it in the beginning and he and Gunter (1956, 1957) discussed the changes which have taken place within the great valley. Gunter (1952) has also discussed some general changes which have taken place around the river's mouth.

At the present time about three fourths of the 35,000-square-mile floodplain area has been cut off from the river by levees. It appears that devegetation of the land also has tended to increase the peaking of annual floods, which means an increase in flood heights. The most disastrous flood of all time came in 1927. Efforts at flood control became coordinated and administered by the Corps of Engineers, U.S. Army, following the 1927 catastrophe.

## RIVER FLOW AND MAJOR FLOODS

### *The Atchafalaya Problem*

Table 1 gives the measured flows of the Mississippi River for each year of the twentieth century in terms of mean flow per second for each year. These figures were furnished by the New Orleans District of the Corps of Engineers. Data before 1900 are unavailable or unreliable.

Today the Mississippi River has two large natural distributaries, the main river and the Atchafalaya. The flows of the two distributaries are given in the same terms. According to Elliott (1932) the Atchafalaya in 1858 carried 77,061 cfs of water during high-water stages. Insofar as the flood or high-water flow is at least around 700,000 cfs in the main river, the Atchafalaya had 10% or maybe even less of the flow in 1858. Since that time the Atchafalaya has grown greatly. This growth has been common knowledge and has been written up in the New Orleans newspapers many times. It was known to early writers such as Mark Twain. In the early 1930s the writer talked to old people who had seen footbridges across the original Atchafalaya Bayou (Gunter 1952) in antebellum days. Apparently, it is an old main channel of the river of a thousand years or so ago, which changed to the left of the direction of flow and is now trying to change back again.

According to Comeaux (1970) a raft in the upper Atchafalaya began to grow sometime between 1500 and 1778, but with Shreve's cutoff, which removed a large oxbow in the main river, the Atchafalaya was virtually bypassed and it decreased in size until 1839, when raft removal was first attempted. In 1861, the process was completed and the Atchafalaya began to grow rapidly. Floods decreased along the lower Mississippi and increased on the Atchafalaya until all farming along that stream came to an end.

**TABLE 1.**

**Mississippi River system flows. This consists of the combined Atchafalaya River flow at Simmesport and the Mississippi River flow at Red River Landing (at Tarbert Landing after June 1963), furnished by New Orleans District, Corps of Engineers, U.S. Army. Figures are in thousands of cubic feet per second and each figure is the mean flow per day for 365 days.**

| Year | Mississippi River at Red River Landing | Atchafalaya River at Simmesport | Combined Flow |
|---|---|---|---|
| 1900 | 432 | 64.7 | 497 |
| 1901 | 377 | 55.4 | 432 |
| 1902 | 461 | 70.2 | 531 |
| 1903 | 639 | 136 | 775 |
| 1904 | 465 | 76.8 | 542 |
| 1905 | 576 | 104 | 680 |
| 1906 | 592 | 103 | 695 |
| 1907 | 676 | 134 | 810 |
| 1908 | 667 | 146 | 813 |
| 1909 | 581 | 105 | 686 |
| 1910 | 473 | 73.7 | 547 |
| 1911 | 459 | 70.6 | 530 |
| 1912 | 646 | 138 | 784 |
| 1913 | 584 | 122 | 706 |
| 1914 | 409 | 69.7 | 479 |
| 1915 | 653 | 126 | 779 |
| 1916 | 640 | 140 | 780 |
| 1917 | 510 | 93.8 | 604 |
| 1918 | 400 | 61.9 | 462 |
| 1919 | 602 | 120 | 722 |
| 1920 | 657 | 145 | 802 |
| 1921 | 527 | 95.4 | 622 |
| 1922 | 566 | 125 | 691 |
| 1923 | 590 | 116 | 706 |
| 1924 | 548 | 98.3 | 646 |
| 1925 | 368 | 50.0 | 418 |
| 1926 | 476 | 98.8 | 575 |
| 1927 | 867 | 239 | 1106 |
| 1928 | 601 | 147 | 748 |
| 1929 | 643 | 177 | 820 |
| 1930 | 419 | 99.8 | 519 |
| 1931 | 283 | 57.8 | 341 |
| 1932 | 516 | 139 | 655 |
| 1933 | 522 | 145 | 667 |
| 1934 | 292 | 71.8 | 364 |
| 1935 | 574 | 177 | 751 |
| 1936 | 346 | 85.5 | 432 |
| 1937 | 514 | 158 | 672 |
| 1938 | 511 | 161 | 672 |
| 1939 | 445 | 143 | 588 |
| 1940 | 313 | 94.9 | 408 |
| 1941 | 376 | 114 | 490 |
| 1942 | 499 | 157 | 656 |
| 1943 | 520 | 165 | 685 |
| 1944 | 475 | 159 | 634 |
| 1945 | 683 | 264 | 947 |
| 1946 | 509 | 202 | 711 |
| 1947 | 426 | 165 | 591 |
| 1948 | 448 | 173 | 621 |
| 1949 | 555 | 226 | 781 |

TABLE 1. (Continued)

| Year | Mississippi River at Red River Landing | Atchafalaya River at Simmesport | Combined Flow |
|---|---|---|---|
| 1950 | 696 | 297 | 993 |
| 1951 | 625 | 256 | 881 |
| 1952 | 466 | 193 | 659 |
| 1953 | 373 | 152 | 525 |
| 1954 | 262 | 94.2 | 356 |
| 1955 | 363 | 139 | 502 |
| 1956 | 332 | 131 | 463 |
| 1957 | 548 | 238 | 786 |
| 1958 | 482 | 233 | 715 |
| 1959 | 382 | 161 | 543 |
| 1960 | 409 | 176 | 585 |
| 1961 | 514 | 236 | 750 |
| 1962 | 475 | 223 | 698 |
| 1963 | 268 | 110 | 378 |
| 1964 | 367 | 105 | 472 |
| 1965 | 416 | 187 | 603 |
| 1966 | 370 | 133 | 503 |
| 1967 | 385 | 170 | 555 |
| 1968 | 434 | 220 | 654 |
| 1969 | 457 | 225 | 682 |
| 1970 | 437 | 216 | 653 |
| 1971 | 388 | 191 | 579 |
| 1972 | 481 | 239 | 720 |
| 1973 | 720 | 377 | 1097 |
| 1974 | 586 | 322 | 908 |
| 1975 | 564 | 310 | 874 |
| 1976 | 374 | 164 | 538 |
| 1977 | 379 | 162 | 541 |
| 1978 | 470 | 202 | 672 |

In the first decade of the present century the Mississippi proper carried 84.5% of the river flow while the Atchafalaya River carried 15.4%. From 1970 to 1978, inclusive, the Atchafalaya carried 32.9% of the total flow and the Mississippi carried 66.1%. The change in the partition of flow has been approximately an 18% decline in 78 years in the Mississipi flow as shown by Table 2, with a commensurate increase in the Atchafalaya. If the present tendency continues, the Atchfalaya River will carry as much water as the Mississippi in about 49 years from the present (1979) or *circa* year 2038. Apparently, aggrandizement by the Atchafalya still continues in spite of attempts by the Corps of Engineers to stop it. In fact, Table 3 shows, in terms of the mean flows for each month, that during the flood year of 1973, the Atchafalaya took over 37% of the flow. Nevertheless, the Old River Control is operated by the Corps to retain approximately the same distribution of flow as would have been obtained under natural river conditions of 1950.

### *The Larger Floods*

Measurements of river flow were not as accurate in the 1800s as they are today, but there are indications (cf. Elliott 1932) that the 1882 flood was about equivalent to those of 1927 and 1973. Thus these three floods are roughly equivalent to 50-year floods.

TABLE 2.

The mean flow of the Mississippi and Atchafalaya rivers in decade intervals from 1900 to 1978 in thousands of cfs. Percentages are given below.

| Decade | Mississippi | Atchafalaya | Totals |
|---|---|---|---|
| 1900–1909 | 546.6 | 99.5 | 646.1 |
| | 84.5 | 15.4 | |
| 1910–1919 | 537.6 | 101.7 | 639.8 |
| | 84.0 | 15.9 | |
| 1920–1929 | 584.3 | 129.1 | 713.4 |
| | 81.9 | 18.0 | |
| 1930–1939 | 442.2 | 123.9 | 566.1 |
| | 78.1 | 21.8 | |
| 1940–1949 | 480.4 | 172.0 | 652.4 |
| | 73.6 | 26.3 | |
| 1950–1959 | 452.9 | 189.4 | 642.3 |
| | 70.5 | 29.4 | |
| 1960–1969 | 409.5 | 178.5 | 588.0 |
| | 69.6 | 30.3 | |
| 1970–1978 | 439.9 | 218.3 | 658.2 |
| | 66.1 | 32.9 | |

The 1927 flood is rated as the most destructive of all time because there were more and greater crevasses in the lower floodplain and no doubt there were greater areas of flooding. In part this is due to the fact that levees were not as good then as they are today. It is also partly because a major portion of the flood control system, consisting of reservoirs on the upper river, the Bonnet Carré Spillway, and the major floodways of the Atchafalaya River, did not exist at that time. Even so the 1973 flood put 13 million acres of the 22-million-acre floodplain under water at one time. Actually about one fourth of the floodplain today is left free and not cut off from the river by levees.

Final data on the combined daily flow of the Mississippi and Atchafalaya rivers, as shown in Table 4, give a lower total flow for 1973 than 1927. Table 4 shows the daily mean flows for each month. It should be noted, too, that the greater flow of the river fell in the first six months during 1973, while in 1927 flood waters lasted for seven months through July.

The 1973 data and the flood data for 1927 were used to calculate the fact that during 1927 the river put 127.0 cubic nautical miles of water into the Gulf of Mexico, whereas in 1973 the figure was 126.5 cubic nautical miles. Figured another way the river flowed an average of 1,106,000 cfs during 1927 and 1,097,000 cfs in 1973 or 63,000 cfs constantly less during the latter year.

So it appears that the 1927 flood was the greatest of record. The 1973 flood was about the same in magnitude and the two were remarkably similar; but the 1973 flood came and went without flooding on the lower river valley. There is no doubt that the Bonnet Carré Spillway and the floodways of the Atchafalaya played an important part during this period of crisis in flood control.

TABLE 3.

Daily discharges for 1973, computed in thousands of cubic feet per second.

Mississippi River at Tarbert Landing, Mississippi

| Day | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 935 | 822 | 759 | 1093 | 1357 | 1216 | 703 | 367 | 247 | 222 | 394 | 599 |
| 2 | 936 | 842 | 722 | 1112 | 1393 | 1191 | 643 | 392 | 241 | 225 | 374 | 656 |
| 3 | 938 | 854 | 686 | 1154 | 1327 | 1159 | 627 | 403 | 239 | 227 | 360 | 700 |
| 4 | 914 | 863 | 654 | 1181 | 1329 | 1126 | 614 | 408 | 239 | 231 | 346 | 740 |
| 5 | 888 | 867 | 620 | 1205 | 1403 | 1070 | 596 | 407 | 238 | 231 | 350 | 767 |
| 6 | 885 | 873 | 594 | 1241 | 1388 | 1090 | 572 | 399 | 237 | 235 | 357 | 785 |
| 7 | 892 | 875 | 580 | 1273 | 1373 | 1045 | 550 | 388 | 234 | 271 | 374 | 798 |
| 8 | 897 | 881 | 565 | 1292 | 1322 | 1054 | 535 | 374 | 232 | 307 | 394 | 826 |
| 9 | 900 | 872 | 559 | 1291 | 1447 | 1029 | 511 | 355 | 230 | 336 | 402 | 844 |
| 10 | 902 | 861 | 563 | 1268 | 1392 | 1037 | 494 | 335 | 228 | 359 | 403 | 861 |
| 11 | 904 | 846 | 582 | 1291 | 1354 | 1012 | 467 | 313 | 229 | 377 | 397 | 878 |
| 12 | 908 | 839 | 591 | 1352 | 1428 | 1014 | 447 | 294 | 232 | 394 | 386 | 892 |
| 13 | 909 | 842 | 618 | 1296 | 1418 | 992 | 441 | 279 | 235 | 408 | 374 | 909 |
| 14 | 908 | 858 | 660 | 1342 | 1426 | 978 | 433 | 269 | 231 | 415 | 362 | 933 |
| 15 | 911 | 868 | 709 | 1335 | 1428 | 983 | 430 | 263 | 227 | 418 | 349 | 946 |
| 16 | 892 | 873 | 745 | 1387 | 1498 | 1003 | 421 | 260 | 223 | 423 | 342 | 954 |
| 17 | 882 | 875 | 780 | 1359 | 1441 | 979 | 414 | 255 | 220 | 427 | 334 | 962 |
| 18 | 867 | 880 | 800 | 1408 | 1440 | 957 | 404 | 254 | 218 | 430 | 328 | 968 |
| 19 | 848 | 885 | 814 | 1323 | 1402 | 975 | 396 | 260 | 222 | 427 | 321 | 950 |
| 20 | 819 | 876 | 833 | 1368 | 1426 | 964 | 384 | 267 | 216 | 425 | 318 | 954 |
| 21 | 796 | 871 | 857 | 1233 | 1409 | 937 | 372 | 277 | 207 | 430 | 311 | 925 |
| 22 | 765 | 866 | 868 | 1286 | 1392 | 910 | 361 | 283 | 218 | 435 | 302 | 886 |
| 23 | 742 | 860 | 887 | 1298 | 1370 | 878 | 350 | 285 | 213 | 439 | 299 | 834 |
| 24 | 708 | 856 | 945 | 1279 | 1361 | 856 | 339 | 291 | 209 | 437 | 305 | 805 |
| 25 | 698 | 849 | 983 | 1285 | 1299 | 856 | 328 | 296 | 207 | 437 | 314 | 801 |
| 26 | 699 | 839 | 995 | 1244 | 1372 | 850 | 319 | 296 | 210 | 439 | 327 | 791 |
| 27 | 709 | 819 | 1005 | 1280 | 1299 | 819 | 300 | 297 | 208 | 434 | 355 | 774 |
| 28 | 727 | 789 | 1021 | 1260 | 1352 | 811 | 293 | 283 | 209 | 430 | 407 | 724 |
| 29 | 751 | | 1041 | 1360 | 1297 | 744 | 294 | 268 | 212 | 427 | 454 | 717 |
| 30 | 767 | | 1054 | 1433 | 1220 | 763 | 308 | 260 | 218 | 420 | 530 | 715 |
| 31 | 792 | | 1072 | | 1207 | | 336 | 256 | | 411 | | 720 |
| Mean | 842 | 857 | 779 | 1284 | 1373 | 977 | 441 | 311 | 224 | 372 | 362 | 826 |
| Max. | 938 | 885 | 1072 | 1433 | 1498 | 1216 | 703 | 408 | 247 | 439 | 530 | 968 |
| Min. | 698 | 789 | 559 | 1093 | 1207 | 744 | 293 | 254 | 207 | 222 | 299 | 599 |

Atchafalaya River at Simmesport, Louisiana

| Day | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 440 | 399 | 406 | 548 | 722 | 661 | 439 | 202 | 129 | 93 | 208 | 290 |
| 2 | 440 | 407 | 404 | 558 | 719 | 674 | 429 | 212 | 126 | 97 | 204 | 312 |
| 3 | 440 | 414 | 385 | 571 | 682 | 648 | 420 | 219 | 123 | 102 | 187 | 330 |
| 4 | 443 | 416 | 368 | 570 | 685 | 601 | 412 | 222 | 125 | 103 | 181 | 347 |
| 5 | 439 | 420 | 351 | 573 | 725 | 625 | 405 | 222 | 128 | 115 | 198 | 342 |
| 6 | 441 | 424 | 339 | 580 | 720 | 620 | 397 | 219 | 136 | 125 | 202 | 341 |
| 7 | 444 | 423 | 333 | 595 | 709 | 579 | 389 | 214 | 141 | 137 | 216 | 348 |
| 8 | 446 | 425 | 332 | 603 | 727 | 607 | 382 | 207 | 143 | 146 | 223 | 361 |
| 9 | 452 | 426 | 330 | 609 | 731 | 606 | 375 | 198 | 142 | 161 | 223 | 375 |
| 10 | 454 | 427 | 326 | 620 | 740 | 549 | 360 | 187 | 141 | 172 | 224 | 390 |
| 11 | 456 | 426 | 331 | 622 | 759 | 562 | 344 | 175 | 141 | 177 | 223 | 403 |
| 12 | 459 | 427 | 340 | 634 | 781 | 570 | 328 | 165 | 142 | 182 | 219 | 399 |
| 13 | 461 | 429 | 347 | 626 | 727 | 542 | 314 | 162 | 148 | 188 | 215 | 398 |
| 14 | 464 | 434 | 357 | 626 | 742 | 552 | 305 | 155 | 156 | 195 | 204 | 401 |
| 15 | 464 | 442 | 376 | 679 | 736 | 574 | 297 | 145 | 155 | 207 | 193 | 416 |
| 16 | 465 | 439 | 401 | 691 | 763 | 528 | 287 | 138 | 150 | 211 | 183 | 418 |
| 17 | 464 | 439 | 414 | 710 | 749 | 530 | 277 | 135 | 145 | 217 | 175 | 421 |
| 18 | 466 | 440 | 424 | 730 | 760 | 539 | 274 | 133 | 140 | 224 | 167 | 414 |
| 19 | 446 | 439 | 433 | 668 | 739 | 546 | 268 | 134 | 122 | 235 | 159 | 414 |
| 20 | 429 | 442 | 441 | 686 | 739 | 550 | 265 | 137 | 121 | 238 | 156 | 407 |
| 21 | 412 | 436 | 445 | 674 | 737 | 534 | 251 | 142 | 121 | 233 | 155 | 387 |
| 22 | 396 | 433 | 454 | 648 | 727 | 515 | 239 | 146 | 101 | 231 | 151 | 384 |
| 23 | 383 | 430 | 462 | 596 | 730 | 503 | 228 | 144 | 109 | 229 | 149 | 375 |
| 24 | 376 | 425 | 483 | 688 | 749 | 513 | 216 | 141 | 113 | 230 | 150 | 373 |
| 25 | 371 | 421 | 499 | 641 | 727 | 463 | 209 | 142 | 112 | 230 | 156 | 373 |
| 26 | 369 | 416 | 513 | 683 | 767 | 492 | 201 | 144 | 101 | 227 | 162 | 372 |
| 27 | 371 | 410 | 528 | 674 | 733 | 475 | 191 | 141 | 91 | 229 | 178 | 366 |
| 28 | 375 | 408 | 523 | 692 | 704 | 472 | 183 | 138 | 89 | 228 | 206 | 361 |
| 29 | 381 | | 521 | 687 | 706 | 472 | 180 | 137 | 90 | 224 | 232 | 356 |
| 30 | 386 | | 531 | 724 | 687 | 452 | 182 | 134 | 92 | 222 | 260 | 352 |
| 31 | 392 | | 539 | | 689 | | 193 | 129 | | 215 | | 351 |
| Mean | 427 | 426 | 417 | 640 | 729 | 552 | 298 | 165 | 126 | 188 | 192 | 373 |
| Max. | 442 | 399 | 539 | 730 | 781 | 674 | 439 | 222 | 156 | 238 | 260 | 421 |
| Min. | 369 | 399 | 326 | 548 | 682 | 452 | 180 | 129 | 89 | 93 | 149 | 290 |

TABLE 4.

Monthly flow of the Mississippi and Atchafalaya rivers in terms of the mean flows computed in thousands of cubic feet per second.

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1927 | 1117 | 1311 | 1395 | 1662 | 2223 | 1818 | 1317 | 601 | 391 | 450 | 348 | 652 |
| 1973 | 1269 | 1283 | 1196 | 1924 | 2102 | 1529 | 739 | 476 | 350 | 560 | 554 | 1199 |

### *The Periods and Times of Great Floods*

De la Vega, the chronicler of De Soto's explorations, recorded a flood that began on March 10, 1543, which was said to have crested 40 days later, and lasted about 80 days. It was said to cover the valley for 20 leagues on each side of the river. In terms of the old Spanish league, this would be a distance of about 105 miles and the flood must have touched both escarpments of the valley. This distance seems to be excessive, but in any case, this was clearly a very large flood 436 years ago. We have nothing to compare it to afterwards. The location was thought to be at Helena, Arkansas.

La Salle recorded another flood in 1664. The French settlers at New Orleans encountered a flood in 1717 and again in 1718 before levees were constructed. The city was flooded by crevasses at least eight times up to 1849. From 1717 to 1816, there were 17 floods recorded on the river

according to the summary given by Elliott (1932, pp. 105–113), but between 1817 and 1916, there were 37 recorded floods. Thus, it would appear that levees brought more floods by raising flood heights, if the flood occurrences were reliably reported. However, Elliott says that they were not well recorded before 1799. As he pointed out, the hydraulics of the river have become much more efficient throughout the years so that the river could accommodate a 2,000,000-cfs flow in 1932, although between natural banks it carried only 1,000,000 cfs.

Also according to Elliott, the 1882 flood was the last typical major one before extensive leveeing. In the 47 years prior to and including 1882, there were 19 floods; in the 47 years from 1883 to 1929, there were 16 floods. Thus, the floods were not increased after 1882 (Elliott 1932, p. 104) although levee and flood heights rose on all the gages* from St. Louis to Carrollton (New Orleans).

Actually there were 37 floods in the 1800s and only 27 floods in the first 80 years of this century, counting flows of over 700,000 cfs as a flood year, including the year 1979, which is not over at this writing. There have been only nine floods in the past 30 years by the same token and 17 in the first 50 years of the century. Actually, Elliott's criteria for floods in the twentieth century presumably were gage heights, crevasses, etc., but since 1927, there have been no crevasses.

Looked at another way, from about 1775 on, it seems that considerable attention was paid to floods and in fact measurements by a gage at Natchez were attempted in 1770. From that year to 1929, inclusive, there were 53 floods listed by Elliott (1932) or a flood every 2.87 years. The annual river flow, as shown in Table 1, is generally very high in flood years, but not always. In 1922, the average flow was only 691,000 cfs but there was a flood, of which Elliott said (1932, p. 114), "The 1922 flood stages were well below previous records at all gaging stations above White River, but from that point to Carrollton they exceeded all previous records." Three crevasses occurred.

Because of the last instance, we have listed as a flood year all years in Table 1 in which the total "instantaneous" flow was above 700,000 cfs. There were 25 such years out of the 78 total during this century so far, giving an average of one every 3.00 years. The approach then seems to be fairly consistent with actual overflows in switching to high-water years with no crevasses as a means of measuring floods. But the idea is also arbitrary and floods listed by Elliott for the century up to 1929 were in years 1903, 1907, 1912, 1913, 1916, 1920, 1922, 1927 and 1929. If the year 1927 is removed from this series, the range and mean cfs of flows were 691,000 to 820,000, and 771,000, whereas the same figures for 1908, 1915, 1919, 1923 and 1928, which were not listed as flood years, were 706,000 to 813,000 and 754,000. It is clear that flood years depend a lot on concentration of river flow in certain months, and a nonflood year may have higher average flows than some flood years. These high-water months are nearly always in the first six or seven months of the year. Some high-flow months also come in the latter part of the year, such as December 1973, and if so they contribute to flooding in the following year.

A great drought on this continent began in the early 1930s and ended in the late 1950s, so that possibly there will be more rain in the next 50 years. In fact, Price and Gunter (1943) pointed out that a change to drier weather took place in south Texas about 1870. The idea of a climatic change was laughed out of court by the scientific community at that time, but it is now recognized that a definite change to drier and warmer weather took place in about 1876 in the United States and was reversed again in the late 1950s, 1957–1958 to be precise.

Today we have high waters or "swells" in the river, as some early writers called them, without any flooding at all outside the levees. And so it is to be hoped that in the future, variations in river flow will be shown by gage heights and cfs readings rather than floods and destruction. This does not mean that all-out leveeing is advocated. Rather it would seem that return to the river of the vast overflow areas between the natural levees and the escarpments of the valley should be effected wherever possible. This would permit lower levees and enrichment of the valley by its natural soils rather than their artificial waste into the sea, which prevails today.

Prior to the flood of 1882, there was not extensive leveeing, but there were accounts of floods by various authorities, according to whom the greatest floods were in 1782, 1785, 1791 and 1809. During the latter year the Natchez gage was installed, and people on the lower river thought the Great Lakes were emptying southward through the river. From then on this gage registered at 48.0 feet and above in 1813, 1815, 1823 and 1828. This gage was at 47.8 in 1858 and 49.0 in 1859. It registered 45.75 in 1882. The St. Louis gage came into use in 1826 and most of the other gages in 1844. These gave more objective information on floods. The years 1840 and 1844 had major floods.

The written accounts of Elliott (1932) and the gage readings indicate that the greatest floods were 1782, 1828 and 1882. Thus 1782, 1828, 1882, 1927 and 1973 would be on 48-year intervals, the so-called 50-year floods. Possibly in 1782, 1828 or 1882 there were 100-year floods, but we have no objective data for precise comparisons. But subjectively the accounts leave little doubt that all of these would rank minimally as 50-year floods.

In 1882, the whole Mississippi floodplain, 34,600 square miles, was reported to have been flooded. The 1927 flood followed high rises on all watersheds contributing to the Mississippi River.

It scarcely seems possible that in a relatively stable geologic and climatic era that the river flow could be multiples of times what it has already been in the last few thousand

*A variant of "gauge" used invariably by the Corps of Engineers.

years. That would mean that the so-called 500- or 1,000-year floods would possibly be less than 100% or twice different from the average.

In any case, we are approaching a 250-year record of the river and there seems to be some evidence for a 50-year cycle of great floods in which the river flows a little less than twice the mean flow for an average year. The known minimum annual flow is 341,000 cfs and the known high is 1,106,000 cfs, the mean being 646,000 or rather close to flood-year flows (700,000 cfs) most of the time. The median is 655,000 cfs. These data are all taken from Table 1. It should be remembered that these figures are the means for the whole year. In 1939, there was one day at Red River Landing when the Mississippi flowed only 85,000 cfs for a day.

According to Elliott (1932, p. 95) climatic experts have estimated that the river flow could vary up to about 3,000,000 cfs, which is 21.4% above the 2,261,000 greatest flow which has been observed. Perhaps this would come with a 500-year flood.

*Some Statistics of Flows*

The mean daily flow of the Mississippi River, as shown by Table 1, ranged from 341,000 in 1931 to 1,106,000 cfs in 1927. The lowest daily combined flow during this 79-year stretch has not been determined but the highest was 2,261,000 on May 16, 1973. The reader should hold in mind that these figures are in terms of the mean flows in cubic feet per second for the whole 24-hour day. The lowest instantaneous flow of the Mississippi proper has been given as 85,000 cfs. For the combined distributaries it must have been 100,000 cfs or a little more.

The statistical measures of the central tendency of an array of figures, such as the Mississippi River flows, are a powerful but simple statistical tool which is often neglected. The mean or average annual flow has already been given as 646,304 cfs. By coincidence, this is almost precisely the annual figure for 1924. In the 1900–1978 time series, 38 years were equal to the mean or below it; 41 years exceeded the mean.

The measurement of the median number shows that it is 655,000 cfs.

The mode of all measurements was at 655,400 cfs, very close to the median. It seems that the central tendency figures are all skewed a little to the left of midpoint or a little less than the point between the extremes. This seems to follow from the fact that the flood and high-water periods are generally not as long or as extensive as the low-water periods, even in some flood years. The years 1927 and 1973 were exceptions. Similarly, Table 5 shows that most flows were in the 500,000 and 600,000 classes, with 53 of the 79 years, or 67%, below 699,000.

In terms of dispersion, the decile annual flows seem to be at 432,000 and 820,000 cfs, and the quartiles are at 531,000 and 748,000 cfs annually. This also shows a certain skewness towards the low side. The standard deviation was calculated to be 159.4 and the coefficient of variation was 0.247.

**TABLE 5.**

**Annual flows of the Mississippi River numbered in class ranges of 100,000 cfs from 300,000 to 1,100,000 for the twentieth century. Figures in thousands.**

| Class Ranges | Annual Flows |
|---|---|
| 300 | 3 |
| 400 | 10 |
| 500 | 17 |
| 600 | 23 |
| 700 | 15 |
| 800 | 6 |
| 900 | 3 |
| 1,000 | 1 |
| 1,100 | 1 |

Inspection of Table 1 shows that high-water years were not particularly associated. In 1903, 1912, 1913, 1916, 1920, 1929 and 1937, there were low-water years (less than 500,000 mean cfs) within the second year before or after a flood year. In contrast, in 1907, 1922, 1950 and 1973, there were high-water years (over 800,000 cfs mean) next to or within the second year of the flood years. In summary, there was continuous high water or a tendency towards several such years together during four flood years, but in seven flood periods the river was variable, so to speak, with high- and low-flow years close together.

One of the lowest river flows of all time occurred in the summer of 1976, three years after the great flood of 1973, and three years before the 1979 flood and the Bonnet Carré Spillway opening.

*Biological Importance of the River*

The river brings down large amounts of nutrient salts and cool, fresh water into the bays and estuaries of Louisiana and Mississippi during the late winter and spring. These factors have large effects on fisheries production of the area but no exhaustive treatment has been presented. Biologists know that oyster reefs are killed by floods (Gunter 1953) and that larval brown shrimp are repelled sometimes by walls of cold, low-salinity water as they try to enter the estuaries during the early months of the year. But an adequate treatment awaits a better and longer series of biological data. This concerns the most productive fishery area on the continent (Gunter 1963) and presumably the information will be forthcoming.

*Ancient Flows*

According to Emiliani et al. (1976), the Mississippi River used to flow 2 to 5 times more than at present, but this was 11,000 to 7,000 years ago when the Wisconsin ice sheet of

North America was melting. The climate at that time was nothing like that of the fairly stable present. During an earlier period of glacier melting some 18,000 years ago, a lake containing some 1,800 cubic miles of water behind an ice dam in Washington, Idaho and Montana, made its way to the Pacific some 330 miles away following melting of the dam. The flow was 10 million cubic meters per second or 345 million cfs or 10 times the combined flows of the rivers of the world (Snow 1976). It dug the Grand Coulee and cleared out the Columbia River Gorge. It was all over in 30 days. Such cataclysmic water flows are simply not characteristic of today's climate.

## CONCLUSIONS AND SUMMARY

In 1900, the Corps of Engineers instituted measurements of the flow of the Mississippi and Atchafalaya rivers, the two distributaries of the Mississippi River system. These are given in cubic feet per second for the whole year as a mean or average figure. A series of 80 integers will have been collected at the end of 1979. The flow has ranged from 341,000 cfs in 1931, four years after the greatest flood, to the greatest annual flow of record in 1927 at 1,106,000 cfs. The mean-annual flow has been 646,000 cfs to the end of 1978. The median is at 655,000 feet and the mode is 655,400 cfs. The decile figures are 432,000 and 820,000 cfs. The quartiles are at 531,000 and 748,000. All of these figures seem to be on the low side or skewed to the left, but most flows are also on the low side and outnumber flood years by two to one, there being one flood in three years.

Since 1928, when the Corps of Engineers took over flood control, there have been virtually no crevasses and levee breaks, and floods are registered by high water, arbitrarily set here with an annual-mean flow of 700,000 cfs. Even so there have been some floods with crevasses at lower flow figures and some high-flow years in the 800,000-cfs class without floods. This comes about because floods depend also on the concentration of runoffs in given months.

The measurements of dispersion show 159,408 cfs for the standard deviation and a coefficient of variation of 0.247, none of which is particularly noteworthy.

Apparently the Atchafalaya carried about 10% of the total flow in 1858. It has grown to approximately 33% of the total flow and, during 1973, it carried 37% of the total flow.

The river's greatest measured flow, 2,261,000 cfs, has been only 6.63 times the mean of its lowest annual flow, 341,000 cfs.

The floods of 1828 and 1882, which covered the floodplain, fit well with 1927 and 1973 as 50-year floods, although the older floods may have been greater. These floods seem to come when all tributaries are contributing heavily. These seem to be about the peak floods that can come under the present climatic regime. The climatologists estimated for Elliott (1932) that the maximum expected flood would be about 3,000,000 cfs. This is only 21.4% greater than the greatest high that has been experienced recently, 2,261,000 cfs, on May 16, 1973. Presumably, the 3,000,000-cfs flood would be a 500- or maybe even a 1000-year flood. With spillways, floodways, reservoirs upstream and strong levees, all operated judiciously along with some sacrifice of the floodplain, it would seem that we could hope to get by such a crises without an overwhelming catastrophe. But such a confrontation between man and the river is certain to come and it must be met with careful planning and relentless vigilance.

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979

# Adaptation of a Brown Water Culture Technique to the Mass Culture of the Copepod *Acartia tonsa*

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DOI: 10.18785/grr.0603.10

*Gulf Research Reports*, Vol. 6, No. 3, 291–292, 1979.

# SHORT COMMUNICATIONS

## ADAPTATION OF A BROWN WATER CULTURE TECHNIQUE TO THE MASS CULTURE OF THE COPEPOD *ACARTIA TONSA*

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*ABSTRACT* The use of bay water, filtered to 5 microns, was found to be sufficiently nutritious to sustain an average of 232,000 adult *Acartia tonsa* per $m^3$. Copepods survived up to 24 days as adults and produced up to 75 nauplii per adult. Nauplii could be sieved to produce copepods of known age or known parentage. Survival of nauplii to adults ranged from 15 to 88%. Culture water varied from 6 to 28°C in temperature, and from 1 to 26 ppt in salinity.

### INTRODUCTION

The usefulness of the copepod *Acartia tonsa* (Dana) as a source of larval fish food and for bioassays involving copepods of known age has generated considerable interest in their culture. Culture systems for copepods have traditionally required the feeding of cultured algae (Kinne 1977). The culture of algae is time intensive and expensive, making it economically impractical to produce the numbers of copepods necessary for larval food.

The use of bay water filtered through a 5-micron GAF filter bag has been found to be sufficiently nutritious to allow the rearing of moderate numbers of copepods at the Gulf Coast Research Laboratory oyster biology facility located at Point Cadet, Biloxi, Mississippi. Nitrate values of ambient water and the resulting phytoplankton, as indicated by chlorophyll-a determinations over several years, were found to be comparable to or exceed values for cultured-algae diets that were being fed to oyster larvae. This has led to the use of the "brown water" technique for the operation of an oyster hatchery (Ogle 1979). The contamination of oyster larval cultures in late summer and fall by *Acartia tonsa* led to the use of the identical techniques for culturing copepods in moderate numbers throughout the winter and spring months.

### MATERIALS AND METHODS

The culturing facility consisted of a 3.9 x 13 m (12 x 40 ft) greenhouse constructed of a double wall of polyethylene (Monsanto 602) stretched over polypropylene pipes anchored to the ground. The copepods are reared in four fiberglass circular tanks of 1890-l (500-gal.) capacity. Bay water is pumped by a 1-hp pump from a pier extending 46 m (150 ft) into Mississippi Sound and passes through a 5-micron filter bag into the culture tanks. The water is not fertilized or aged. The tanks are stocked with approximately 1 million copepods and the water is completely changed three times weekly. The tanks are drained through 2.54-cm (1 in.) pipes into a sieve box which filters out the copepods before the water flows to a waste drain. Drains and air lines are changed with each water change. Tanks are hosed out, scrubbed and allowed to air dry between changes. Aeration is provided in each tank by a single stone from a vibrator pump.

The copepods used for stocking were recruited from the wild by holding tanks of unfiltered water for several days and then removing the stage animals desired. By culturing unstocked tanks containing bag-filtered water it was demonstrated that no recruitment occurred from using water passed through a 5-micron filter.

The various stages of copepods can be separated readily by utilizing sieves of various sizes. A 212-micron sieve will retain only the adults, allowing copepodites and nauplii to pass through. The copepodites will be retained by a 100-micron sieve and the nauplii by a 45-micron sieve. If copepods of known parentage are desired, one can sieve a mixed population, retain the adults, and in the following change retain the nauplii from those parents. If animals of known age are required, the tanks can be sieved daily, thereby concentrating all nauplii hatched within the preceding 24 hours. These nauplii are then reared to maturity in separate tanks. After three changes during a week's period, the nauplii will have grown to adults. On the fourth change (9 days), these copepods will themselves be producing nauplii.

Contrary to previous reports of sensitivity to handling (Gentile and Sosnowski 1968), these copepods were handled somewhat roughly as they were routinely sieved and concentrated into 10 l of water, stirred with a plunger plate, and a 1-ml sample withdrawn and enumerated to estimate the total number of animals.

Manuscript received August 31, 1979; accepted September 28, 1979.

## RESULTS

Copepods were reared from November 1978 until May 4, 1979. During November and December, five successive generations were reared. Naupliar production and survival were followed for one generation during the month of December, and production of an additional generation was followed during April (Table 1). Naupliar production ranged from 2.3 to 75 nauplii per adult for the month of December and ranged from 2.2 to 10 nauplii per adult for the April brood. The copepods survived as adults for about 20 days during December and 24 days during April. Survival of the nauplii varied from 17 to 69% during December and 15 to 88% during April. During these studies, a life cycle was completed in 9 to 12 days.

Temperature ranged from a low of 5.5°C to a high of 27.7°C averaging 20°C, while salinity ranged from a low of 1 ppt to a high of 26 ppt averaging 12 ppt over the culture period.

## DISCUSSION

Copepods have been reared in fertilized ponds previously (Raymont and Miller 1962) with densities of 100 and 200 per liter of water. However, several species were mixed and no control was possible over the population. Bay water was used in 1-gallon jars by Heinle (1966) in his rearing experiments for producing small numbers of copepods. The production from the system used here averaged 232,000 adults per $m^3$ which is 580 times the maximum concentration of copepods found in adjacent waters (McIlwain 1968). This was accomplished simply by removing competitors and predators and without fertilization or supplemental feeding. Production from these tanks was excessive to the requirements of bioassay purposes and experimental larval fish-rearing, but cannot meet the needs for mass fish-rearing projects. The results are encouraging and it is possible that with supplemental feeding, better handling techniques and more constant culture conditions, even higher yields might be achieved.

TABLE 1.

Naupliar production and survival of *Acartia tonsa* during the months of December (1978) and April (1979).

| Date | Brood | Parents | Numbers Produced | | | Nauplii per adult | Survival % |
|---|---|---|---|---|---|---|---|
| | | | Nauplii | Copepodites | Adults | | |
| 12/14 | 1 | 180,000 | 410,000 | 300,000 | 70,000 | 2.3 | 17 |
| 12/18 | 2 | 160,000 | 1,200,000 | 1,000,000 | 830,000 | 7.5 | 69 |
| 12/22 | 3 | 80,000 | 2,000,000 | 1,100,000 | 1,300,000 | 16.4 | 65 |
| 12/26 | 4 | 20,000 | 1,500,000 | 830,000 | – | 75.0 | – |
| 12/30 | 5 | 20,000 | 540,000 | – | – | 27.0 | – |
| 4/ 3 | 1 | 80,000 | 720,000 | – | 220,000 | 9.0 | 31 |
| 4/ 9 | 2 | 70,000 | 700,000 | – | 490,000 | 10.0 | 70 |
| 4/16 | 3 | 60,000 | 130,000 | – | 20,000 | 2.2 | 15 |
| 4/23 | 4 | 50,000 | 170,000 | – | 150,000 | 3.4 | 88 |

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**Gulf Research Reports**

Volume 6 | Issue 3

January 1979

# Diet of the Periwinkle *Littorina irrorata* in a Louisiana Salt Marsh

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DOI: 10.18785/grr.0603.11

*Gulf Research Reports*, Vol. 6, No. 3, 293–295, 1979.

# DIET OF THE PERIWINKLE *LITTORINA IRRORATA* IN A LOUISIANA SALT MARSH

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*ABSTRACT* The diet of the periwinkle *Littorina irrorata* was examined. The food substrate utilized most frequently in the field was dead *Spartina alterniflora*. The primary component of the stomach and feces was vascular plant particles. Plant particles, even though a major portion of the diet, were egested unaltered in feces. Other food substrates contributed significantly to the diet. Marsh sediment was utilized by 37% of all snails observed to be feeding, while 4% grazed on live *S. alterniflora*. Algal mats, present on several occasions during the study, were utilized extensively. Comparison of microbial components in dead *S. alterniflora* and marsh sediment with those in the stomach and feces indicated that members of the microbial community of food substrates were assimilated.

## INTRODUCTION

*Littorina irrorata* Say is prevalent in salt marshes from Long Island, New York, to Port Isabel, Texas (Bequaert 1943). Tissue biomass of snails averages 10 g/m$^2$ in Georgia (Smalley 1958) and 5 g/m$^2$ in Louisiana (Day et al. 1973). Despite the prevalence of the species, little information is available on its diet. The animal has been classified as a detritus-algae feeder in several studies (Smalley 1958; Teal 1962; Day et al. 1973), but feeding analyses are not reported. The only feeding study is that by Marples (1966), who injected $^{32}$P into live *Spartina alterniflora* and marsh sediment with subsequent assay of *L. irrorata* tissue. Radioactivity was not detected in snail tissue when $^{32}$P was injected into live plant tissue. However, when $^{32}$P was sprayed onto the sediment surface, animal tissue became highly labeled with the isotope. From these results, Marples (1966) concluded that *L. irrorata* is primarily a detritus feeder.

The present study, initiated to determine the diet of *L. irrorata*, included analysis of food substrates utilized in the field and analysis of stomach and feces content.

## MATERIALS AND METHODS

### *Study Area*

The study area was a *Spartina alterniflora*-dominated salt marsh in the southwestern section of the Barataria Bay system of coastal Louisiana. This system is described by Day et al. (1973). Population densities of *L. irrorata* in the study area were determined at distances of 4, 6, 8 and 10 m into the marsh. A 0.25 m$^2$ ring was tossed over the shoulder in one direction. Snails inside the ring on sediment and plant surfaces were enumerated. A total of 96 such determinations, made over a 7-month period, yielded a population density of 24 ± 14 snails per m$^2$.

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Manuscript received November 27, 1978; accepted March 9, 1979.

### *Food Substrates Utilized in the Field*

*Littorina irrorata* exhibits periods of both activity and inactivity in the field. For this reason, preliminary studies were conducted to determine the factors controlling periods of feeding. Animal activity and the presence or absence of food in the stomach were related to tide and air temperature as these environmental conditions affect the movement of *L. irrorata* (Smalley 1958; Bingham 1972). These preliminary studies revealed that animals were active and stomachs were full when three conditions prevailed: (1) a water level below the marsh; (2) a daily tide range covering the marsh during a 24-hour tidal cycle; and (3) an air temperature of 14°C or above.

Feeding was examined during seven periods from June to May when the above environmental conditions prevailed. A transect 6 m from and parallel to the marsh edge was established, and all active animals along this transect observed. A snail was recorded as active and feeding if its foot was creeping over the substrate and the head was in contact with the substrate. The substrate utilized by each active snail was tabulated as live (green) *S. alterniflora* (stems or leaves), dead (brown) *S. alterniflora* (attached stems and leaves, or outer sheaths of live plants), or marsh sediment. No distinction was made between utilization of marsh sediment and algal mats during two periods when the latter were available. From 130 to 247 active snails were observed during each feeding period.

### *Stomach and Feces Analysis*

Snails observed to be feeding were randomly collected from the field and immediately placed in a 1-liter beaker containing ice. Snails were held on ice until completion of stomach analysis, within 6 hours. The shell was broken with a hammer and the animal removed. The stomach was opened with a dissecting needle, and the contents withdrawn with a capillary pipette or a dissecting needle. Stomach contents were placed on a microscope slide, covered with a cover slip, and analyzed with a light microscope at 100x, 400x and

1,000x magnification. The types and relative abundance of material present were recorded.

Fecal pellets were collected from field-gathered snails held at ambient air temperature in a 1-liter beaker. Pellets were dissected in sterile seawater on a glass slide, the mixture covered with a cover slip, and examined with a light microscope at 100x, 400x and 1,000x magnification. The types and relative abundance of material present were recorded.

## RESULTS

Dead *Spartina alterniflora* contributed 90% of the diet of *L. irrorata* during one feeding period and was utilized extensively during all periods (Table 1). Marsh sediment was used frequently, except during June. During five of the seven periods, utilization of dead *S. alterniflora* and marsh sediment was more or less equal. Live *S. alterniflora* was grazed during five of the seven periods, but by no more than 11% of the snails observed feeding at any one period.

**TABLE 1.**

**Percentage of food substrates utilized in the field by *L. irrorata*.**

| Date | No. observed feeding | *S. alterniflora* Live | *S. alterniflora* Dead | Marsh sediment |
|---|---|---|---|---|
| 17 June | 153 | 11 | 80 | 9 |
| 18 June | 171 | 9 | 90 | 1 |
| 16 July | 206 | 2 | 51 | 47 |
| 14 August | 247 | 1 | 45 | 54 |
| 24 October | 164 | 0 | 41 | 59 |
| 7 January | 130 | 0 | 54 | 46 |
| 12 May | 203 | 3 | 54 | 43 |
| Total | 1,274 | $\bar{x}$ = 4 | $\bar{x}$ = 59 | $\bar{x}$ = 37 |

Algal mats were an additional food substrate utilized on occasion. This substrate covered large areas of the marsh surface during two periods of the study. During these periods snails grazed the mats frequently.

The stomach contents of 90 snails observed to be feeding contained vascular plant and clay particles as the dominant components. Approximately 75% of the stomachs examined contained vascular plant particles as the primary component, while the remainder contained predominantly clay particles. All stomachs contained considerable numbers of filamentous algae and diatoms. Their presence was particularly noticeable during the two periods when algal mats were present. Additional components of stomachs included nematodes, foraminifera, ostracods, mites, copepods and microorganisms (bacteria, yeasts and molds).

The primary fecal components, vascular plant and clay particles, were mixed and compacted to form the pellet. Other fecal components included diatoms, broken diatom frustules, filamentous algae, foraminifera, mites, bacteria, yeasts, fungal hyphae and spores. Fecal pellets of snails feeding on dead *S. alterniflora* contained an average of 339 plant particles/pellet, ranging from 4 to 4,358. The mean size of plant particles was 0.47 x 0.12 mm, with a range of from 1.10 x 0.02 to 1.63 x 0.25 mm. The abundance of particulate plant particles in feces indicated the efficiency of the snail radula in grazing the plant substrate, and the inability of the snail digestive system to assimilate this ingested material. Plant particles ingested were egested with no significant alteration.

## DISCUSSION

The food substrate utilized most frequently in the field by *L. irrorata* was dead *S. alterniflora*. Of 1,274 snails observed to be feeding, 59% utilized this substrate (Table 1). The frequent use of this food substrate explained the dominance of vascular plant particles in the stomach and feces. Vascular plant particles, even though a major portion of the diet, were passed out in the feces without significant alteration.

Although dead *S. alterniflora* was the major portion of the diet of *L. irrorata*, other food substrates contributed significantly to the diet. Marsh sediment was the second most utilized substrate, being the food of 37% of all snails observed to be feeding (Table 1). Live *S. alterniflora* was never utilized extensively by *L. irrorata*, but was grazed by 4% of all snails observed to be feeding (Table 1). Algal mats were a significant portion of the snail diet whenever these were present. The intermittent presence and utilization of this food substrate through the year may be an important contribution to the diet of the snail, since fresh algae have a higher organic matter content and caloric value than plant detritus (Odum 1970).

Studies on the microbial community of dead *S. alterniflora* and marsh sediment were conducted in conjunction with the diet studies. These studies demonstrated the abundance of microbial organisms associated with dead *S. alterniflora* and marsh sediment (Table 2). Comparison of microbial components in dead *S. alterniflora* and marsh

**TABLE 2.**

**The microbial community of dead *S. alterniflora* and marsh sediment.**

| Members* | Dead *S. alterniflora* | Marsh sediment |
|---|---|---|
| I. Autotrophic | | |
| A. Diatoms | $2.9 \times 10^6$ | $8.1 \times 10^5$ |
| B. Other algae | $7.7 \times 10^2$ | $9.8 \times 10^2$ |
| II. Heterotrophic | | |
| A. Microorganisms | | |
| 1. Bacteria | $1.5 \times 10^9$ | $6.7 \times 10^7$ |
| 2. Fungi | $2.6 \times 10^6$ | $3.3 \times 10^5$ |
| 3. Protozoans | $2.4 \times 10^3$ | $5.4 \times 10^2$ |
| B. Meiofauna | | |
| 1. Nematodes | $1.3 \times 10^3$ | $3.1 \times 10^2$ |
| 2. Others | $1.2 \times 10^3$ | $5.1 \times 10^2$ |

*Based on mean numbers per gram wet weight calculated from 3 to 8 replicates. Algae, protozoans, and meiofauna were enumerated using direct microscopic techniques. Bacteria and fungi were enumerated on Marine Agar 2216 (Difco) and M12a (Meyers et al. 1970), respectively.

sediment with those in stomach and feces indicated that some members of the microbial community of these two food substrates were assimilated. Ciliated protozoans, although numerous in food substrates, were absent in stomach and feces samples, indicating their absorption during passage through the gut. Nematodes were abundant in foods, and present in stomachs, but were absent in feces, indicating their digestion. The presence of broken diatom frustules in both stomachs and feces, and the presence of empty and lysing algal sheaths in stomachs, suggested that these microbial components were assimilated. A number of studies have demonstrated that microbial organisms associated with detritus substrates are assimilated by a wide variety of coastal consumers (Newell 1965; Adams and Angelovic 1970; Odum 1970; Fenchel 1970; Chua and Brinkhurst 1973; Wetzel 1977).

ACKNOWLEDGMENTS

This paper is a portion of a dissertation submitted to the Graduate Faculty of Louisiana State University, Baton Rouge. Dr. Samuel P. Meyers served as major advisor. The research was supported by the Louisiana Sea Grant Program, part of the National Sea Grant Program maintained by the National Oceanographic and Atmospheric Administration.

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## Gulf Research Reports

Volume 6 | Issue 3

January 1979


# Localized Plankton Blooms and Jubilees on the Gulf Coast


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*Gulf Research Reports*, Vol. 6, No. 3, 297–299, 1979.

# LOCALIZED PLANKTON BLOOMS AND JUBILEES ON THE GULF COAST

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*ABSTRACT* The writers describe various small types of plankton blooms such as those occurring in boat slips, the head of a large bayou and a strip type bloom of *Chaetoceras* on the Gulf beach. Oyster kills from "poison water" draining off of marshes are said to be caused by plankton bloom. Small "jubilees" are said to be caused by localized blooms and one of these is described as it occurred.

In November 1938, Dr. Margaretha Brongersma-Sanders visited Walvis Bay, South Africa, where fish kills were commonly reported as being caused by hydrogen sulfide. She came to the conclusion that the kill was caused by a plankton bloom and that the hydrogen sulfide was a result and not the cause of the mass mortality (Brongersma-Sanders 1943).

When the senior author joined the Texas Game, Fish and Oyster Commission as its second marine biologist in 1939, his first job was to investigate a recurring summer fish kill in Offatts Bayou in Galveston. The area is a deep hole at the inner, blind end of Offatts Bayou, separated from the rest of the bayou by the 61st Street causeway of Galveston. Gunter (1942) thought that organic material caused these boils of hydrogen sulfide and "milky" water. Later, Mrs. J. B. Cross (Connell and Cross 1950) of the Medical School at Galveston attributed this mortality to a plankton bloom of *Gonyaulax* and she published a note on it in *Science*. Both J. W. Hedgpeth (1951) and the senior author (Gunter 1951) replied to her in print, disagreeing with her ideas. However, Gunter realized years later that the lady was correct.

Many times, the senior author has also observed small plankton blooms in the blind ends of boat slips around fish houses and shrimp factories. Presumably this results from organic material thrown into the water and not dispersed.

A peculiar localized plankton bloom followed a spell of rainy weather when the sea was calm and glassy along the Gulf beach of Mustang Island. It is quite out of the ordinary for south Texas; he saw the glassy calm twice during 20 years. Corpus Christi holds the record as the windiest city in the United States, the average wind speed being about 11 miles per hour all the time. Following rainy weather and the flat, glassy calm, a narrow band of diatom bloom developed along the beach extending out 15 or 20 yards. The water turned brown, somewhat like murky tea, and contrasted with the yellowish-green Gulf, which clarifies greatly during periods of still water. The bloom consisted of billions of *Chaetoceras* sp., a common open sea diatom. Presumably this bloom takes place next to the beach when nutrients are washed out by the rains and the water becomes still. It was traced to the south end of Mustang Island, a distance of some 16 miles, and it extended to Padre Island and on out of sight.

There is another unrecognized bloom which has been reported several times. Actually it is a type of mortality. The trouble is generally said to be caused by "poison water" coming from somewhere, usually the marshes. A spell of rain takes place following a long dry spell, and it is reported that black and poisonous water carries down into the bays and kills the inhabitants, including oysters. The fact is nothing poisonous is generated in the marshes by a long dry spell. Some components are washed out of the marsh by rains, and a plankton bloom is stimulated. This is characteristic of a great many plankton blooms including the Florida red tide (Gunter et al. 1948).

This is the case even with plankton blooms in freshwater ponds. Many workers with a marine or freshwater laboratory or even a college laboratory are acquainted with a common complaint: "Day before yesterday we had a big rain and last night all my fish died. I think poison washed off from the land next door." But the plaintiff will also tell you that the color of the pond water changed to green, red or rusty brown. These kills may be caused by poisonous elements of the plankton even in fresh water, but then too, freshwater kills usually take place in the middle of the night and may be said to be from oxygen lack. In the bays the same oxygen deficiency will occur and this will cause oysters to close up. According to Dr. J. G. Mackin (personal communication) if the oysters are heavily infected with *Perkinsus marinus*, or if they have to close due to oxygen lack, or because of a heavy influx of fresh water, they die very quickly. This phenomenon is not easily documented and although there have been several reports in state conservation agencies, etc., printed references are difficult to find. One was given in the *Eleventh Biennial Report* of the Louisiana Department of Conservation for the year 1932–33. The heaviest rainfall in the history of the New Orleans weather office was said to have occurred in a 2-week period in July and the water

Manuscript received May 1, 1979; accepted May 8, 1979.

was held back in the marshes by strong south winds until it became saturated with rotten vegetation and it was poisonous to oyster life. A similar instance happened about 6 years ago in Escambia Bay, Florida. It was never published but the area was examined by biologists of both the state and federal government and a private concern. Suits were filed because oysters were killed. The state and federal biologists reported that these oysters were heavily infected with *Perkinsus marinus* and they felt that this offered some connection. Actually there was a sharp salinity change which apparently caused the oysters to close; also there was a plankton bloom in part of the bay.

Conversations over such matters as these brought forth the following information which was written by Mr. Charles H. Lyles, formerly Head, Statistical Division, National Marine Fisheries Service, later Director, Mississippi Marine Conservation Commission, and now Executive Director of the Gulf States Marine Fisheries Commission.

Because of the paucity of knowledge of occurrences and causes of jubilees* on the Mississippi Gulf coast, Lyles decided to record as much as he knows of them at the present time and to add to this as they occur.

To the best of Lyles' knowledge a jubilee was first described to him by a man named Gussie Cruse in August of 1940. Cruse had just speared about (estimate) 150 pounds of flounder along the beach west of the mouth of Graveline Bayou. Apparently jubilees were "old hat" to him.

As an infrequent visitor to the Gulf coast during the next decade, Lyles' knowledge of jubilees was limited to descriptions by individuals who participated in them.

In the early 1950s, however, Bellefountain Beach became more populated and consequently the jubilees appeared to be more numerous. Possibly it was a case of closer observations, with the result of more sightings.

Jubilees occur on Bellefountain Beach most often in the early morning hours between midnight and daylight. Lyles has observed only one during daylight hours. This occurred Friday morning, August 27, 1971. It was during this jubilee that he reached the conclusion that the event is triggered by a dinoflagellate bloom. It was centered at the mouth of a small bayou that empties into Mississippi Sound on Bellefountain Beach just south of a community swimming pool owned by Ocean Beach Estates. The total length of the bayou is not more than 1 mile. The jubilee spread about 1 mile to the west and ½ mile to the east of the mouth of this small stream. The area could be clearly delineated by the color of the water. It was a yellowish-brown. Flounders, eels, crabs, small menhaden and miscellaneous species seemed to be affected.

A breeze sprang up about 9:30 a.m. and the water became mixed, color disappeared, and life returned to normal except that many dead fish, such as small flounders, hogchokers, small menhaden and eels lay dead on the beach for some time.

Another known jubilee occurred August 4, 1972. Lyles was not present.

On August 5, 1973 at about 1:00 a.m., the water became a dark tea color at the mouth of Graveline Bayou close to the Benefield Place (Leaning Oaks) on Bellefountain Beach. There were no outright kills, but crabs, shrimp, flounders and lots of baby sea cats became sluggish and showed all the symptoms of a jubilee.

On August 18, 1973 from 3:00 a.m. to daylight, the largest jubilee Lyles ever observed extended from Graveline Bayou west to St. Andrews cut, and perhaps farther. There were crabs, lots of eels, some croakers, lots of menhaden, lots of flounders, a few stargazers and other miscellaneous species dead and dying in red-colored water.

In general, jubilees occur during a neap tide and most likely with a very, very slight movement of air from the north. They are not seen to happen in turbulent water. They occur most often from late July to early September. To Lyles' knowledge none have ever been observed in cool weather. They are always accompanied by a discoloration of water in the affected area and usually occur during drainoff after a heavy rain shower.

## SUMMARY

The point of these remarks is to call the reader's attention to the fact that there are localized plankton blooms taking place at many locations and many times up and down the Gulf coast. They have also been reported on the Atlantic coast. They appear to be responsible for many localized cases of fish kills. Their onset is often characterized as following rainy weather and a few days of calm. It thus appears that some land component or components are washed down by the rains into waters near shore. Whether or not these are the usual fertilizer salts or some trace element that acts as a chelating agent is not known.

Such phenomena seem to occur more frequently than they did in the past, probably because of increased nutrients flowing into our salt waters in recent years due to various activities of man.

Several types of unicellular organisms seem to be involved. Two of them are known, *Chaetoceras* and *Gonyaulax*. No human ailment has been reported from the eating of crustaceans or fish caught during a jubilee. However, it is now well recognized that a toxic substance is produced in blooms of naked dinoflagellates.

*Jubilee is the name given to fish kills, usually as they are seen developing, along the Gulf coasts of Alabama and Mississippi. They have been observed as far west and south as Corpus Christi Bay, Texas. The largest and most notorious one took place on the east shores of Mobile Bay, Alabama, and it may have had a different cause than the one given here (cf. Loesch 1960).

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


## Occurrence of Microalgae in Southwestern Louisiana Coastal Salt Flats


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DOI: 10.18785/grr.0603.13

*Gulf Research Reports*, Vol. 6, No. 3, 301–303, 1979.

# OCCURRENCE OF MICROALGAE IN SOUTHWESTERN LOUISIANA COASTAL SALT FLATS[1]

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*ABSTRACT* A descriptive analysis of the edaphic algal flora in salt flats along the coastline of southwestern Louisiana is provided. Six salt flats containing the angiosperm *Salicornia* were surveyed in November 1978, and April 1979, for microalgae. Seven genera of Chrysophycophyta, eleven genera of Cyanochloronta, and eighteen genera of the Chlorophycophyta were found. The most abundant alga was *Oscillatoria* (sensu Drouet). The most common green alga was *Chlorosarcinopsis.*

## INTRODUCTION

There have been few studies of edaphic microalgae along the coast of the Gulf of Mexico. The most notable reports are those of Sorensen and Conover (1962), Dykstra et al. (1975), Sage and Sullivan (1978) and Sullivan (1978). Other reports on the algal flora of inland saline soils include those of Nordin and Blinn (1972) and MacEntee and Bold (1978). Such studies typically report the presence of numerous genera of green and blue-green algae as well as diatoms and dinoflagellates (Round 1965).

The purpose of this study was to provide a descriptive analysis of the edaphic algae found in salt flats along the coast of Louisiana. Six salt flats located in the coastal salt marshes of southwestern Louisiana between the Mermentau and Sabine rivers were surveyed (Table 1). All of the sites are located above mean high tide and are irregularly flooded by fresh water from precipitation. The soil sediment (upper 2 cm) is composed primarily of clays and fine silt with no significant amounts of organic debris. Each of the edaphic habitats was devoid of spermatophytes. The prevalent angiosperm species bordering these sites were *Distichlis spicata* (L.) Greene, *Salicornia bigelovii* Torr. and *Suaeda linearis* (Ell.) Moq.

## MATERIALS AND METHODS

Four soil samples to a depth of 2 cm were collected at each site on November 14, 1978, and April 10, 1979. These samples were analyzed for pH using a 1:1 water-soil slurry with a Markson Model 90 meter. Salinity was measured using a 2:1 water-soil slurry with a YSI Conductivity Bridge Model 31. Rainfall data were obtained from the National Oceanic and Atmospheric Administration (NOAA) Climatological Station at Rockefeller Wildlife Refuge. The soil samples were assayed for the presence of algae by the technique of enrichment culture as described by Brown and Bold (1964).

TABLE 1.

Location of study sites along the coast of southwestern Louisiana, arranged from east to west.

| Site No. | Area | Parish | Latitude/Longitude |
|---|---|---|---|
| I | Rutherford Beach | Cameron | 29° 45.2′ N<br>93° 05.9′ W |
| II | Cameron Jetties | Cameron | 29° 45.1′ N<br>93° 20.1′ W |
| III | Cameron Jetties | Cameron | 29° 45.2′ N<br>93° 20.1′ W |
| IV | Louisiana Helicopter Heliport | Cameron | 29° 45.5′ N<br>93° 20.1′ W |
| V | Holly Beach | Cameron | 29° 45.2′ N<br>93° 25.4′ W |
| VI | Johnson's Bayou | Cameron | 29° 45.1′ N<br>93° 35.9′ W |

## RESULTS

The pH of the soil samples ranged from 8.07 to 8.95 and showed no seasonal fluctuation. Salinity varied from a low of 8 ppt at site III in the fall to 38 ppt at site IV in the spring. The mean salinity for all sites was 18 ppt. The total precipitation for November 1978 was 7.14 inches and 4.55 inches for April 1979.

Examination of the enrichment cultures after a 2-week incubation period revealed a rich microalgal flora (Table 2). Seven genera of the Chrysophycophyta were identified and diatoms were predominant. The most common diatoms belonged to the genera *Navicula, Nitzschia,* and *Amphora.* Eleven genera of the Cyanochloronta were found and the most frequent were *Anabaena, Oscillatoria* (sensu Drouet, 1968), and *Schizothrix.* Eighteen genera of the Chlorophycophyta were found. Some of these had to be isolated and subcultured to facilitate identification, and the most common genera were *Chlorococcum, Chlorosarcinopsis,* and *Tetracystis.* Several genera of diatoms and one dinoflagellate were observed only once and, in the absence of sufficient material, remained unidentified. Of all the algae reported in Table 2, *Oscillatoria* was the most abundant.

[1]This study was supported by McNeese State University Faculty Grant No. 11–01.

Manuscript received August 13, 1979; accepted September 26, 1979.

**TABLE 2.**

**Distribution of microalgae found in six salt flats along the coast of southwestern Louisiana.**

| | November 1978 | | | | | | April 1979 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Site No. | | | | | | Site No. | | | | | |
| Classification: | I | II | III | IV | V | VI | I | II | III | IV | V | VI |
| Chlorophycophyta | | | | | | | | | | | | |
| *Ankistrodesmus* | | | | | | | + | | + | + | + | |
| *Bracteococcus* | | | + | | + | | | | | | | |
| *Chlamydomonas* | + | + | + | | | + | + | + | | | | + |
| *Chlorella* | | + | | | | | | + | | | | |
| *Chlorococcum* | + | + | + | | + | + | + | + | + | + | + | + |
| *Chlorosarcina* | | | | | | + | | | | | | |
| *Chlorosarcinopsis* | + | | + | + | + | + | + | + | + | + | + | + |
| *Gleocystis* | | | | | | | | | | | | + |
| *Klebsormidium* | | + | + | | | | | | | | | + |
| *Microspora* | | | | | | | | | | | + | |
| *Pedimonas* | | + | | | | | | | | | | |
| *Pleuastrum* | | + | + | | | | | + | | | | |
| *Radiosphaera* | | | | | | | | | | | + | |
| *Rhizoclonium* | | | | | + | + | | | | | | + |
| *Spongiochloris* | | | | | | | | | | | + | |
| *Stigeoclonium* | | | | | | + | | + | | | | + |
| *Tetracystis* | + | + | + | + | | | + | | + | + | | |
| *Ulothrix* | | | | | | + | | | | | | |
| Chrysophycophyta | | | | | | | | | | | | |
| *Amphora* | | + | | + | | | | + | | + | | |
| *Botrydiopsis* | | | + | | | | | | | | | |
| *Chrysosarcinia* | | | | + | | | | | | | | |
| *Fragilaria* | | + | | | | + | | + | | | | + |
| *Navicula* | + | + | + | + | + | + | + | + | + | + | + | + |
| *Nitzschia* | + | | | | | + | + | | | | | + |
| *Ochromonas* | | | | + | | | + | | + | | | + |
| Cyanochloronta | | | | | | | | | | | | |
| *Anabaena* | + | + | + | + | + | | + | + | | + | + | |
| *Aphanotheca* | + | | | + | | | + | | | | | |
| *Calothrix* | | | + | | | | | | + | | | + |
| *Chroococcus* | + | | + | | | | + | | | | + | |
| *Microcoleus* | | | | | + | | | | | | | |
| *Microcystis* | | | + | + | | | | | | | | + |
| *Nodularia* | | | + | + | | | | | | | + | |
| *Nostoc* | | | + | | | | | | + | | | + |
| *Oscillatoria* | + | + | + | + | + | + | + | + | + | + | + | + |
| *Schizothrix* | + | + | + | + | + | + | + | | + | + | + | + |
| *Spirulina* | + | + | + | | | | + | + | + | | | |
| Totals | 12 | 13 | 19 | 12 | 9 | 12 | 14 | 12 | 11 | 9 | 12 | 16 |

## DISCUSSION

Differences in the total number of genera between the fall and spring flora were probably due to the decreased precipitation in the spring of 1979; this is particularly true of site III which drains a freshwater ditch. The high ratio of blue-green to green algae in this study may be due to the alkaline nature of the soils. The Cyanophyceae and Bacillariophyceae have been previously described as growing best in alkaline conditions (Lund 1946, Baker and Bold 1970, MacEntee et al. 1972, and Brock 1973). The diversity of blue-green algae in this study compares favorably with that reported by Sage and Sullivan (1978) for a Mississippi salt marsh. Although there were fewer genera of diatoms found in our study than reported for a coastal salt marsh by Sullivan (1978), the diatom flora of the salt flats compared favorably with that found in saline prairie soils by Nordin and Blinn (1972).

Brock (1973) stated that the green algae are the least sensitive to pH and are almost universal in occurrence in soils. However, one genus, which is reported to be sensitive to pH, is *Chlorosarcinopsis* (McComb and Maples 1979). Olson (1961) reported this genus to be characteristic of Wisconsin pine forests and their acidic soils. McComb and Maples (1979) reported *Chlorosarcinopsis* as rare in the acid soils (pH 4.6 to 5.2) beneath a slash pine canopy. Chantanchat and Bold (1962) found *Chlorosarcinopsis* to be a prevalent genus in arid alkaline soils. Dykstra et al. (1975) reported that *Chlorosarcinopsis* was the most abundant alga in the coastal soils of Texas (pH 6.2 to 6.7). In this study, we found *Chlorosarcinopsis* to be the most common green alga in the alkaline coastal soils of Louisiana.

A number of environmental parameters have been suggested as important factors affecting the distribution of soil algae. These include moisture, light, organic matter and phytotoxins. We believe that soil pH is one of the most important factors affecting the frequency and occurrence of soil algae, particularly in view of the known sensitivities of blue-green algae to low pH values. Further studies are needed concerning the effect pH has on the distribution of edaphic green algae. Such studies should consider sensitivities to pH values and distribution patterns at the species level.

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Gulf Research Reports

Volume 6 | Issue 3

January 1979

# Notes on Sea Beach Ecology. Food Sources on Sandy Beaches and Localized Diatom Blooms Bordering Gulf Beaches

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DOI: 10.18785/grr.0603.14

*Gulf Research Reports*, Vol. 6, No. 3, 305–307, 1979.

# NOTES ON SEA BEACH ECOLOGY. FOOD SOURCES ON SANDY BEACHES AND LOCALIZED DIATOM BLOOMS BORDERING GULF BEACHES

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*ABSTRACT* Food production along sandy beaches is much different from that of rocky beaches. No large algae grow on sand beaches. Small filamentous green algae find footholds upon molluscs, mole crabs, strands of *Leptogorgia* and logs. Basic food along the sand beach is made up of diatoms, bacteria, unicellular algae and detritus; diatoms are probably the most abundant autotrophic organism; the beach bacteria are largely heterotrophic. Most food on sandy beaches comes from the sea. The sandy shore seems to be barren, but it swarms with plant and animal life. Food production has a seasonal aspect. Food strands more abundantly on sandy beaches because the force of water returning to the sea is much less than that coming in. Beach materials are concentrated in a strand line. All organic materials are returned to the food cycle. Beached animal remains are consumed immediately until their breakdown products ooze away to enrich the sand substrata. The material of logs may not be redistributed until a number of years have passed. Food producing algae are diatoms, green algae, peridinians and blue-greens. Many of them are quite small and must be detected by bacteriological methods. They are probably quite significant. Food production from autotrophic algae appears to be relatively steady compared to drifting materials, which may vary enormously. Various types of food drift in as a result of dinoflagellate blooms, catastrophic cold kills and stranding cetaceans. Seasonal drifting materials such as sargassum, *Leptogorgia* and jellyfish come in at particular times of the year. The river mouth floods bring in material. The artificial jetsam of ships washes up on the beaches.

Nutrients and salts are also concentrated on beaches from organic remains. As a result, a type of beach-hugging planktonic bloom has been noted on the Texas coast when the sea is calm following heavy rains. It consists of a yellowish-brown conglomeration of diatoms of the species *Chaetoceras* sp., 15 to 20 feet wide along the shore for many, many miles. It follows heavy rains and the event is parallel to some aspects of the Florida red tide which occurs in calm weather, often following heavy rains, which are thought to bring chelating substances from the land.

There are variations in time both in production of food on beaches and that washing in from the sea. Quantitative studies have not been made; nevertheless, certain nonquantitative observations and distinctions can be made.

Food production and the sources of food for animals living along sand beaches are considerably different from those of rocky beaches. In contrast to rocky shores, no large algae grow on sand beaches except for filamentous green varieties which find small footholds upon certain molluscs such as *Donax*, the mole crab *Emerita*, strands of the alcyonarian coral *Leptogorgia*, and other beached objects such as logs. They occur only in negligible amounts. Thus the basic food along the sand beach is microscopic plants, chiefly diatoms, bacteria, various other unicellular algae and detritus. The diatoms are probably the most abundant autotrophic organisms produced on the beach. Presumably the beach bacteria are largely heterotrophic. Most of the food consumed on sandy beaches comes from the sea. Pearse et al. (1942, p. 137) have made similar comparisons before and their words are worth quoting, "A marine sandy beach seems like an inhospitable place for plants and animals to become established. On a rocky, wave-beaten headland, where storms rage and intertidal areas are exposed alternately to cool, surging water and hot or cold desiccating air, there may be an abundant biota of attached seaweeds, hydroids, barnacles, clams, etc. The rocks may be literally carpeted with living things. On the other hand a shifting, sandy beach is usually without much apparent life. There may be seen an occasional scuttling crab, a school of little fishes wiggling into the shallows, or a solitary sandpiper drilling holes with his long beak. In general a sandy shore seems to be a barren, clean place – admirable for bathing, but unpromising as a habitat where a biologist may collect or study animals. But appearances are deceiving. Marine littoral sands swarm with plant and animal life."

Along both rocky and sandy beaches food production has a seasonal aspect on temperate coasts, and the total production or peaks change from year to year. Nevertheless, this process has aspects of steadiness and regularity. Possibly the same thing holds for drift of planktonic materials from the sea, but information on that point is lacking.

There is a second fundamental difference between the sand beach and the rocky beaches in that the rougher and more abrupt the beach, the less organic materials, especially large particles or bodies, tend to strand and add their increment to the food of the shoreline. This holds true for two reasons. Rocky beaches are generally not wide and the water from waves and tide is channeled into quite strong currents returning to the sea. Floating objects may bump or bounce against rocks, which act as more or less pointed bodies, and be swirled out to sea again long before they ground on relatively level bottom. This is not to imply that stranding does not take place on rocky coasts, for it sometimes does and the total frequency may even be high, but the tendency is less than on an even-bottomed sand beach. The amount of food stranding on rocky coasts will

Manuscript received April 9, 1979; accepted April 19, 1979.

be at a maximum on gravelly or cobblestone beaches, which are not greatly different from sand beaches, and decreases with increasing roughness of the substrate and size of the rocks. On the bluff-like rock walls which prevail on some coasts, nothing strands except negligible scraps in small clefts and cracks.

In contrast, everything which drifts into the surf of a sandy beach finally strands. The writer has pointed out before that returning currents are much weaker than those driving in from the sea and that all floating materials become beached where they drag bottom (Gunter 1946). Another factor which serves to further reduce the ability of breaking waves to carry flotsam (and sediments) seaward again was pointed out by Dr. David DeVries (personal communication). This is because part of the water from any breaking wave train percolates into the beach, to return slowly to sea level at that particular stage of the tide. This percolation (or loss of water) on the foreshore portion of the beach is most effective in reducing energy of return flow for the more gently slopping, sandy beaches. Stranding holds true for whale carcasses and other large objects and for microscopic animals and plants as well. Subsequent higher tides may move beached objects higher up on sandy beaches, but they are not carried back to sea. Thus there is an aspect of finality about the stranding or beaching process. This is especially true of the wide Gulf beaches, where, except for a few days a month, tides are negligible and occur only once a day. Hedgpeth (1957, pp. 590–591) discussed the sorting action of strong and weak currents of incoming and outgoing waves with regard to sand, beached organisms and "the usual flotsam." It is only reversed by extreme flooding from land or actual cutting away of the beach by currents, both of which are rare occurrences. Beaching has been so commonly observed that it has given rise to a descriptive term, i.e., the strandline. The flotsam of the ocean, extending as a line down the beach, is characteristic of this environment all over the world. Thus, although sand beaches are harsh environments fitted only for the hardier organisms, they are not poor in food. To the contrary, food materials from a wide area are concentrated there within a narrow band.

It goes without saying that all organic materials drifting into the beach are returned in some manner to the food cycle. Even the logs and grass stems are slowly broken down by bacteria, while the more edible products are consumed directly and immediately, both by permanent beach dwellers and certain land animals which remove organic materials away from the beach cycle. In this latter category the various birds probably play the greater part.

Food-producing algae, according to Humm (Pearse et al. 1942), aside from the few macrophytes, are diatoms, green algae, peridinians and blue-greens. Some are only 3 microns in size and are seldom abundant enough to be seen. However, they are to be found everywhere by bacteriological methods and Humm states that they are probably more "significant in the economy of the beach than previously supposed."

Food production on the beach is relatively steady from autotrophic algae while that from drifting materials varies enormously in abundance. This matter has not been noted particularly in the literature and it is worth some attention. One group of drifting materials may be called sporadic or irregular. There are many examples over the world but only certain ones which have been observed personally will be mentioned.

During the various cases of catastrophic mortality in the sea, huge numbers of animals, chiefly fishes, drift onto the beach. Photographs relating to dinoflagellate bloom or the red tide in Florida (Gunter et al. 1948) and others connected with cold kills on the Texas coast (Gunter and Hildebrand 1951) have been published. Although the latter are of bay beaches, the writer (Gunter 1941) has noted that numbers of molluscs and fishes also wash up on the outside of beaches after the heavy cold kills. When these catastrophic mortalities come, and they are fairly common in widely spaced places on earth, the beach fauna receives a vast superabundance of food.

It is well known that carcasses of cetaceans commonly come ashore. Numbers of locality records derive from such instances. Some species are prone to stranding in large numbers while alive and large porpoises of the genus *Globicephala* are especially noted for this characteristic. Lowery (1943) published photographs of 49 of these animals that had become beached on the Louisiana coast following a hurricane. There are several other examples in the literature. Animals such as the ghost crabs *Ocypode* gather around such carcasses and dine upon the rich fare until the liquefying remains ooze away into the sand.

A second group of drifting materials may be called seasonal. On the Texas coast during the spring, vast windrows of *Sargassum* pile up on the beach. In certain years this drift is much greater than in others. In 1950 a band approximately 15 yards wide and 1 foot deep lined the Texas coast for over 300 miles. The weights involved must have been of the order of several thousand tons. During the summer the alcyonarian coral, *Leptogorgia setacea* (Pallas), rolls ashore in large masses and to such an extent that some thoughts have been given to the possibility of commercial use of the central horny core as a source of iodine. Still later in the year, when the winds blow from the north, thousands of the jellyfish *Stomolophus meleagris* Agassiz are sometimes beached. It should also be mentioned that *Physalia* and *Velella* move steadily into the strandline throughout the summer, but are relatively scarce in winter.

Certain beaches around river mouths, such as those of the Louisiana coast, receive influxes of material from land following the annual spring high-water periods. The amounts are greatly increased in flood years. These materials consist largely of plant remains, such as logs and the water hyacinth. The logs and dead trees sometimes make the beaches virtually impassable.

In addition to the purely natural causes of organic deposition upon the beach, there are certain artificial ones, some of which have a seasonal character. Beaches near ship lanes or in the vicinity of coastwise traffic receive certain amounts of garbage. Trash materials from commercial fishermen's catches seasonally drift up on some beaches. Near Port Aransas, Texas, certain fishes, chiefly tarpon, drift ashore in considerable numbers in summer due to the sport fishing industry of that town.

Food materials drifting onto beaches may be roughly divided into two categories on a basis of whether their availability is immediate or deferred. Most animal remains are immediately available to the beach animals. On the other hand, plant remains must first be subjected to bacterial action and, in some cases, it may be years before they become totally available. Even the most edible animal bodies are not all consumed before part of them oozes away into the sand. These factors tend to have a damping or time-spreading effect upon the amounts of food available to beach animals following mass beachings; part of the food may become available over a time spread of a few weeks, months or even years after mass strandings.

Humm (Pearse et al. 1942) made a particular study and found that the various bacteria species that destroy the celluloses and hemi-celluloses are quite common. They slowly destroy logs many years after their stranding. Chitinoclastic bacteria have been found abundant on both Atlantic and Pacific beaches.

It is clear that organic material drifting into the beaches varies enormously from time to time and this variation may be seasonal or completely sporadic, with some instances being years apart. Seasonal drifts usually cover a few hundred miles. The sporadic cases may relate to a few hundred miles of beach, but certain others, such as the strandings of cetaceans are entirely local. In any case, the concentration of organic materials in a narrow band on the shores of the seas is impressive.

Pearse et al. (1942, p. 176) concluded "Sand beaches are not barren wastes, as they appear at first glance, but are swarming with life, and continually digest and furnish food to plants and animals."

The shifting sands of the seashore are probably not good sites for the process of fossilization. Nevertheless, the mere fact that the beaches are points of concentration makes them worthy of consideration in this respect. Fossils of open-sea animals have been described from beach deposits. It is obvious that remains of land animals and plants might also be found along old beach lines.

It seems probable that nutrient salts are also concentrated upon beaches, as would be expected from concentration of organic remains. This is suggested by a type of plankton bloom which occurs along the Texas coast. When the water of the Gulf is relatively calm, following heavy rains, a narrow band of diatoms sometimes forms along the Gulf shore of Mustang Island, extending from the water's edge out 15 or 20 yards. The writer has seen it running along the shore without break for a distance of 16 miles, which was as far as it was traced, and extending on out of sight. The organisms were so thick they gave the water a yellowish-brown appearance somewhat like tea. The phenomenon has been observed two or three times and the organisms in one instance were collected in a plankton net by the late David Kramer (personal communication). He found that the water contained a perfectly uniform population of billions of *Chaetoceras* sp., which is commonly looked upon as an open-sea genus. Presumably, this diatom bloom takes place next to the beach when the common nutrient salts are leached out by rainwater and remain concentrated in the calm sea right next to shore, or they may wash down a chelating agent from land, as has been suggested for the Florida red tide. In any case, the parallel of blooms following rains and calm weather is suggestive.

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


# Notes on the Genus *Probythinella* Thiele, 1928 (Gastropoda: Hydrobiidae) in the Coastal Waters of the Northern Gulf of Mexico and the Taxonomic Status of *Vioscalba louisianae* Morrison, 1965


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DOI: 10.18785/grr.0603.15





## Recommended Citation

Heard, R. W. 1979. Notes on the Genus *Probythinella* Thiele, 1928 (Gastropoda: Hydrobiidae) in the Coastal Waters of the Northern Gulf of Mexico and the Taxonomic Status of *Vioscalba louisianae* Morrison, 1965. Gulf Research Reports 6 (3): 309-312.
Retrieved from http://aquila.usm.edu/gcr/vol6/iss3/15

*Gulf Research Reports*, Vol. 6, No. 3, 309–312, 1979.

# NOTES ON THE GENUS *PROBYTHINELLA* THIELE, 1928 (GASTROPODA: HYDROBIIDAE) IN THE COASTAL WATERS OF THE NORTHERN GULF OF MEXICO AND THE TAXONOMIC STATUS OF *VIOSCALBA LOUISIANAE* MORRISON, 1965

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*ABSTRACT* The gastropod genus *Probythinella* Thiele, 1928, is considered a senior synonym of *Vioscalba* Morrison, 1965. *Probythinella louisianae* (Morrison, 1965) n. comb. tentatively is recognized as a valid species distinct from the closely related *P. lacustris* (Baker, 1928) and *P. protera* Pilsbry, 1953. The eastern range of *P. louisianae* is extended to Mobile Bay, Alabama. Limited observations on the habitat and reproduction of *P. louisianae* are reported.

## TAXONOMY

Confusion has existed concerning the taxonomy of the gastropod genera *Probythinella* Thiele, 1928, and *Vioscalba* Morrison, 1965, which have been reported from brackish water of the northern Gulf of Mexico. During the past several years, in conjunction with various benthic and parasitologic studies, I have collected and observed large numbers of *Probythinella* from estuarine areas in this region. Using these observations and the existing literature, I have been able to clarify the taxonomic status of the genus *Vioscalba* and to give an opinion on the specific identity of the northern Gulf populations of *Probythinella*.

Two species of the genus *Probythinella* Thiele, 1928, have been described; both are known only from North America. *Probythinella lacustris* (Baker, 1928), a freshwater species, has been reported from central Canada and from the central United States as far south as Arkansas (Hibbard and Taylor 1960). The second species, *P. protera* Pilsbry, 1953, was described from "fossil" shells taken from Pleiocene deposits near Tampa Bay, Florida (Pilsbry 1953). Solem (1961) reported a living population of *P. protera* from estuarine habitats in Lake Pontchartrain, Louisiana, and concluded that other living gastropod species were known from the Pleiocene period and that the phenomenon was not as significant as it would seem. There also is the possibility that Pilsbry's specimens of *P. protera* were of recent origin and were not fossil shells. William G. Lyons (personal communication, 1979) indicated that the type locality for *P. protera*, a dredge-fill area, has a mixture of recent and fossil mollusk shells.

Without referring to Solem's (1961) study, Morrison (1965) described a new genus and species, *Vioscalba louisianae*. He reported large populations of this gastropod from Lakes Pontchartrain and Borgne, and dead shells from Hopedale, Louisiana, and Heron Bay, Mississippi. Morrison further stated that *V. louisianae* and *P. protera* were closely related but distinct species, and transferred *P. protera* to the genus *Vioscalba*. The name *Vioscalba louisianae* has been used for this species in subsequent publications (Tarver and Dugas 1973; Dugas, Tarver and Nutwell 1974; Tarver and Savoie 1976; Andrews 1977). Andrews reported *V. louisianae* to be a common brackish-water species along the Texas coast. She listed it under the family Stenothyridae and mentioned that it might be a synonym of *V. protera* [=*Probythinella protera*]. I have compared my material with published descriptions of *P. lacustris*, *P. protera* and *V. louisianae*. I also have examined shells of *P. lacustris* from Ohio in the collections of the Florida State Museum. Based on these observations, especially the similarity of the male copulatory organs (verges) and the shells, I conclude that the genus *Vioscalba* Morrison, 1965, definitely is a junior synonym of *Probythinella* Thiele, 1928.

The specific designation for living populations of *Probythinella* occurring in estuarine areas of the northern Gulf is more difficult to determine with certainty. Morrison (1965) distinguished *P. protera* from *V. louisianae* as follows: "*V. protera* has a more abruptly truncated spire; the body whorl and the penultimate whorl of *protera* are flatter toward the suture; in contrast all whorls of *louisianae* are more regularly rounded from suture to suture. The shells of *louisianae* appear markedly more obese than the specimens of *protera* seen." Solem (1961) reported that *P. protera* appeared to be closely related to the freshwater species, *P. lacustris*, which has its earliest known occurrences in the late Pleistocene (Hibbard and Taylor 1960). Considerable variation in shell morphology of *P. lacustris* had been reported, and this variation, coupled with other factors, created considerable taxonomic confusion. Hibbard and Taylor (1960) clarified the taxonomy of *P. lacustris*, listing its synonyms and summarizing what was known of its biology. Concerning intraspecific variation they stated: "There is no warrant for taxonomic recognition of the known variation within *Probythinella lacustris*." Solem (1961) also noted considerable variation in the shell morphology within the population of *Probythinella protera* from Lake Pontchartrain and stated that the constricted aperture of *P. protera* was the most consistent

Manuscript received September 4, 1979; accepted October 3, 1979.

difference between the two species. He further suggested that the constricted aperture of *P. protera* and two other gastropods, *Texadina sphinctostoma* Abbott and Ladd, 1951, and *Amphithalamus dystatus* Pilsbry and McGinty, 1950, might be "a convergent response to some unknown ecological factor in the Gulf Coast estuarine environment, since it has occurred in [their] three distinct lineages."

Shell variation within the northern Gulf populations of *Probythinella* is great enough to make them nearly, if not completely, indistinguishable from the fossil shells of *P. protera*, as well as some of the shell forms of *P. lacustris*. Figure 1 illustrates two shells of *Probythinella* from Lake Pontchartrain showing differences in their spires and apertures. The soft parts are illustrated in Figure 2, which shows the pigmentation of the mantle and visceral mass (A) and two aspects of the male copulatory organ, the verge (B, C).

If *P. protera sensu* Pilsbry, 1951, proves not to be a fossil form and extant populations are found in the Tampa Bay area, a careful comparison of the verge, radula, pigmentation pattern, and other morphological features of the soft body parts of this species with those of the northern Gulf populations of *Probythinella* will be needed to determine if they are conspecific or distinct species. If, on the other hand, *P. protera* is a true fossil species, its specific status in relation to *P. lacustris* and the brackish-water forms from the northern Gulf of Mexico becomes largely a matter of taxonomic conjecture.

Based on the information available, three taxonomic options exist concerning the specific name for the populations of *Probythinella* occurring in the northern Gulf: (1) all known specimens of *Probythinella*, including fossil and brackish-water forms, are variants or ecotypes of a single species—*P. lacustris*; (2) all fossil and living specimens of the genus from coastal areas of the Gulf of Mexico are *P. protera;* (3) there are three distinct species presently known in North America—*P. lacustris* (Baker, 1928); *P. protera* Pilsbry, 1953; and *P. louisianae* (Morrison, 1965). Pending additional collections and biological studies, I accept the third option and recognize *Probythinella louisianae* (Morrison, 1965) n. comb. as a distinct species, which is conspecific with *P. protera* sensu Solem, 1961. If living specimens of *Probythinella* with constricted apertures characteristic of *P. protera* and *P. louisianae* should be collected in brackish-water areas along the west coast of Florida near the Tampa Bay area, then option 2, or Solem's (1961) designation for the northern Gulf specimens as "*P. protera*," will probably be correct, with *P. louisianae* becoming its junior synonym. Detailed morphologic, ecologic, physiologic, and behavioral comparisons of *P. lacustris* and *P. louisianae* will be needed to

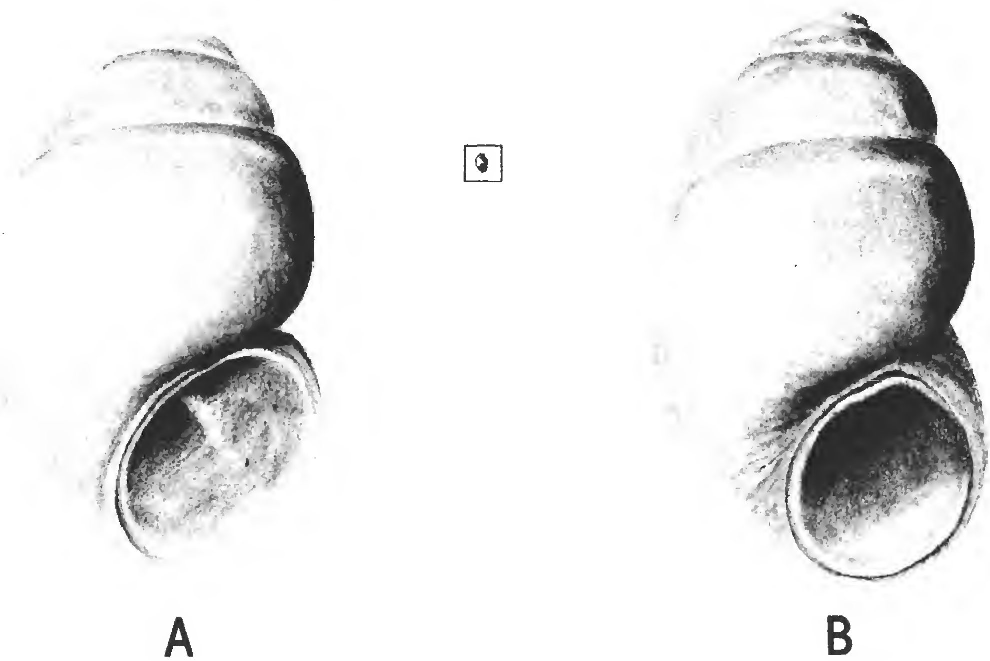


**Figure 1.** ***Probythinella louisianae*** **(Morrison, 1965) from Lake Pontchartrain, Louisiana; shells A and B demonstrate morphological variation from same population; specimen within box represents life size of adult snail.**

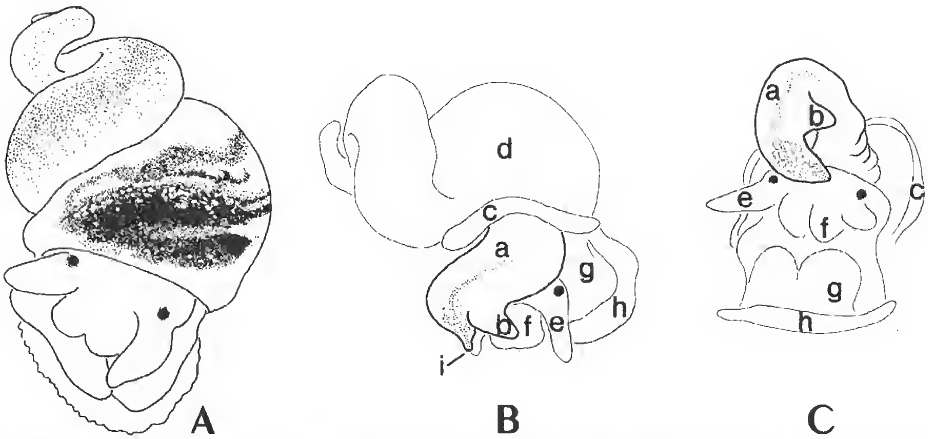


**Figure 2.** *Probythinella louisianae* (Morrison, 1965) from Lake Pontchartrain, Louisiana; A–adult female, dorsal aspect (shell removed), showing pigmentation on mantle and visceral mass; B–adult male, dorsal aspect (shell removed); C–adult male, frontal aspect; a–verge (penis), b–single lobe on convex margin of verge, c–edge of mantle, d–visceral mass, e–tentacles, f–snout, g–foot, h–operculum, i–opening of sperm duct (vas deferens) at tip of verge.

refute or validate option 1. Cross-breeding experiments between the two species would be especially useful.

## BIOLOGICAL NOTES

I have made some limited observations on the distribution, ecology, and reproduction of *P. louisianae,* which are included here as a possible stimulus for futher study. I have found *P. louisianae* in several locations east of its published range–in Mississippi (St. Louis Bay, Back Bay of Biloxi, Davis, Simmons, and Heron bayous, and the West Pascagoula River) and in Alabama (mouth of East Fowl River and Mobile Bay). The Alabama record extends the known eastern range of *P. louisianae* approximately 113 kilometers. My attempts to find this species in a number of areas along the eastern Alabama and western Florida coasts, including Escambia, Appalachicola and Tampa bays, were unsuccessful; however, my collections were limited, leaving the possibility that *Probythinella* may still occur in these areas.

Specimens of *P. louisianae* collected during this study were all from areas with low salinities, usually less than 10 ppt and in some instances approaching freshwater conditions. Living specimens were always found subtidally, usually in water depths greater than a meter. The largest concentrations occurred on fine sand-silt bottoms, but some specimens were occasionally found in muddy areas. My observations of specimens maintained in the laboratory indicate that *P. louisianae* usually occurs partly covered by the bottom sediment or just under it. As the snails move through the sediment they leave distinct tracks. I never observed specimens of *P. louisianae* penetrating deeper than 3 to 4 mm into the sediment. A number of other invertebrates occurred in association with *P. louisianae,* including *Texadina sphinctostoma* Abbott and Ladd, 1951; *Neritina reclivata* (Say, 1822); *Rangia cuneata* (Gray, 1831); *Mulinia* sp.; *Macoma mitchelli* Dall, 1895; *Mytilopsis leucophaeta* (Conrad, 1831); *Corophium lacustre* Vanhoffen, 1811; *Hargaria rapax* (Hargar, 1879); *Hypaniola florida* (Hartman, 1951); *Streblospio benedicti* Webster, 1879; and chironomid midge larvae. The smooth, cream-colored shells of *P. louisianae* were often fouled with reddish-brown or rust-colored encrustations. These encrustations appeared to be due, at least in part, to small invertebrate (turbellarian?) egg cases and associated microflora.

While maintaining *P. louisianae* in glass culture bowls in the laboratory, I observed female snails depositing egg capsules on hard surfaces, including pieces of dead shell and wood, the shells of other *P. louisianae*, and the bottoms and sides of the culture bowls. Each newly deposited egg capsule contained a single egg in an early stage of cleavage. When viewed dorsally, the capsules were circular with diameters of 0.5 to 0.6 mm. In lateral aspect, the capsules were dome-shaped with flattened proximal surfaces attached to the substrate by a mucoid adhesive. After 8 to 12 days of development, a small juvenile snail with fully formed protoconch emerges from each capsule. There is no planktonic veliger stage, and the newly hatched snails crawl about on the bottom sediments and begin feeding.

*Probythinella louisianae* can occur in relatively large numbers, often exceeding 1,000 per square meter, but little is known about its bionomics. Morrison (1965) reported that the snails are eaten by wild ducks; however, there are no other published data on their impact on the estuarine food chain as either consumers or prey for other organisms. It is probable that *P. louisianae* and its even more numerous gastropod associate *T. sphinctostoma* play an important role in the reworking and enrichment of the sediments on which

they occur. My observations indicate that both these snails are deposit feeders. Individuals of either species, despite their small size (2.5 to 3.5 mm shell length), consume a considerable amount of bottom material and daily produce large numbers of fecal pellets. The ecological and nutritional importance of fecal material from estuarine and marine invertebrates and its probable role in the food web have been discussed and documented by Newell (1965), Johannes and Satomi (1966), Frankenberg, Coles, and Johannes (1967), Frankenberg and Smith (1967), and Kraeuter (1976). Since *P. louisianae* and *T. sphinctostoma* often occur in great numbers over large areas of bay bottom, studies are needed of their nutritional and overall ecological impact on northern Gulf estuarine systems.

ACKNOWLEDGMENTS

This study was supported in part by a grant entitled "Helminths of the Gulf of Mexico" from the State of Mississippi to R. M. Overstreet, and by a contract (No. DACN–29–77–C–02 53) from the U.S. Army Corps of Engineers to the Center for Wetland Resources, Louisiana State University. Appreciation is extended to B. Heard for preparing the illustrations, and to R. M. Overstreet and Walter B. Sikora for their constructive comments and suggestions on the manuscript. Fred G. Thompson kindly allowed me to examine specimens of *P. lacustris* in the collections of the Florida State Museum.

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# Gulf Research Reports

Volume 6 | Issue 3

January 1979


## First Record of a Bloom of *Gonyaulax monilata* in Coastal Waters of Mississippi


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DOI: 10.18785/grr.0603.16

*Gulf Research Reports*, Vol. 6, No. 3, 313–316, 1979.

# FIRST RECORD OF A BLOOM OF *GONYAULAX MONILATA* IN COASTAL WATERS OF MISSISSIPPI

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*ABSTRACT* Data are presented on a bloom of the toxic dinoflagellate *Gonyaulax monilata* in coastal waters of Florida, Alabama, Mississippi and Louisiana. This paper documents the first record of a bloom of this species in Mississippi Sound and adjacent Gulf of Mexico.

## INTRODUCTION

Red tides resulting from toxic dinoflagellate blooms are a common phenomenon in the coastal waters of Florida and Texas. Periodic blooms of the unarmored dinoflagellate *Gymnodinium breve* have created both economic hardships and public health problems for residents of the Florida west coast for over 100 years. *Gymnodinium breve* tides occur most frequently from Anclote Keys off Tarpon Springs to the Florida Keys (Joyce and Roberts 1975). Toxic red tides in northern Gulf waters more often are associated with blooms of the armored dinoflagellate *Gonyaulax monilata.*

Howell (1953) first described *G. monilata* and found it was associated with discolored water and small fish kills on the east coast of Florida near Melbourne. He also identified this dinoflagellate as the causative organism for the red water and fish kill reported by Connell and Cross (1950) from Offats Bayou, Galveston, Texas (Wardle et al. 1975). Gates and Wilson (1960), Marvin (1965), Marvin and Proctor (1965), Ray and Aldrich (1966) and Wardle et al. (1975) have since documented the occurrence of summer blooms of *G. monilata* in the Galveston area. Williams and Ingle (1972) studied a *G. monilata* bloom associated with a fish kill from the west coast of Florida, establishing the first record of its occurrence in offshore waters.

Red tides caused by toxic dinoflagellate blooms have not been reported from Mississippi Sound, although phytoplankton blooms causing discolored waters are a frequent occurrence during warmer months. The senior author observed extensive blooms of the blue-green alga *Oscillatoria erythraeum* in waters near the offshore barrier islands in August 1974 and July 1976. Small localized blooms along mainland beaches may be responsible for the "jubilees" that occur periodically (Gunter, personal communication).

## MATERIALS AND METHODS

Aerial surveys were made on August 14, 17, 21, 29 and on September 25, 1979, to monitor the bloom and map the affected areas in Mississippi waters. A number of investigations were conducted by boat to collect samples of the organism and to check for fish kills. Cell counts were made from dip samples taken in areas of intense water discoloration. After measuring the volume of the sample, it was gently mixed and an aliquot withdrawn. The aliquot was placed in a settling chamber for a period of 24 hours. The organisms were identified and counts made in 50 fields (chosen randomly) at a magnification of 250X using a Zeiss inverted microscope equipped with phase contrast. Determination of numbers of organisms per liter was made using the following formula:

$$\text{cells/liter} = \frac{\dfrac{\text{number}}{\text{counted}}\left[\dfrac{\text{total area}}{\text{area covered}}\right]\left[\dfrac{\text{concentrated volume}}{\text{aliquot volume}}\right]}{\text{liters filtered}}$$

Observations by personnel of the National Marine Fisheries Service (NMFS) Laboratory in Pascagoula, Mississippi, and reports from local fishermen were also recorded.

## RESULTS AND DISCUSSION

Reports of red water in the vicinity of Ship Island Pass were received by Gulf Coast Research Laboratory personnel on 8 August 1979. Analysis of samples taken on 9 August confirmed the presence of large numbers of the dinoflagellate *G. monilata.*

*Gonyaulax monilata* is a small, sub-spherical armored dinoflagellate that appears somewhat flattened through the antero-posterior axis. It characteristically forms chains of up to 40 cells in length (Figure 1), but also may exist as single cells (Howell 1953). The incidence of long chains in a bloom serves as an index of the growth phase (Aldrich et al. 1967). Rapidly increasing populations have the highest percentages of individuals in long chains, while short chains of two and four cells are more common during the stages of maximum and declining numbers.

The initial aerial survey on 14 August located extensive

Manuscript received October 11, 1979; accepted October 15, 1979.

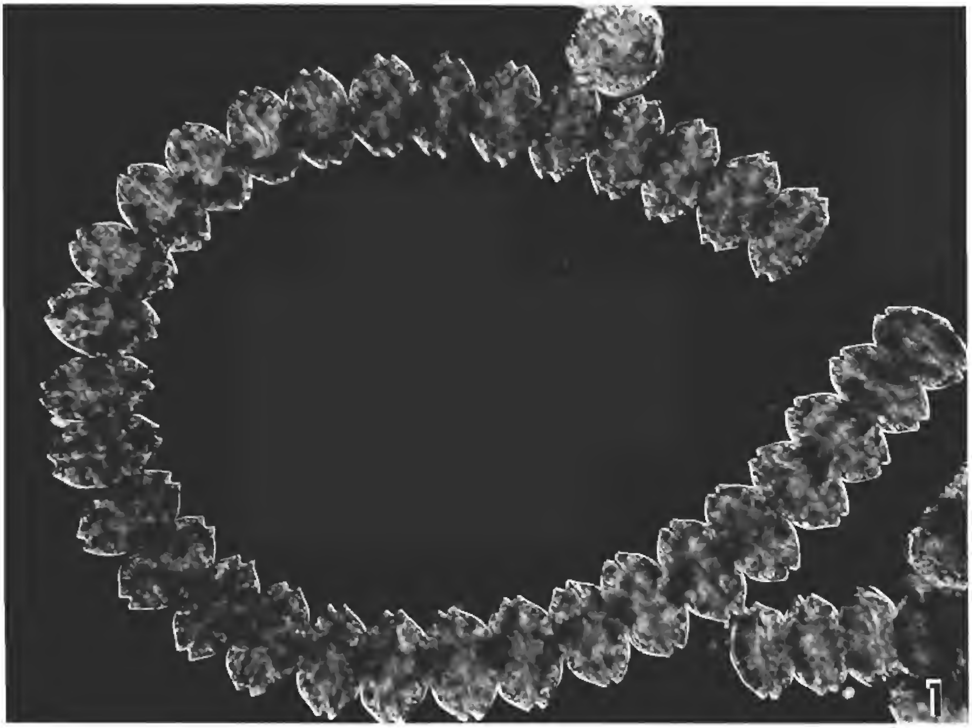

**Figure 1. A photomicrograph of *Gonyaulax monilata* showing the long chain structure characteristic of this dinoflagellate. Normarski differential interference contrast, X 210.**

areas of discolored water in the western sector of Mississippi Sound and adjacent Gulf of Mexico (Figure 2).

Heaviest concentrations of the organism were found between Cat and Ship islands. Long streaks of red water were noted south of these islands extending into upper Chandeleur Sound, Louisiana. Large patches of discolored water were observed in Mississippi Sound to the north of Cat Island reaching to within 3 miles of the mainland in the Pass Christian area. Smaller patches occurred south of Horn and Petit Bois islands and near Round Island, south of Pascagoula.

A similar pattern of distribution was noted on 17 August, although the water discoloration was less intense. On 21 August, the bloom appeared to be dissipating (Figure 3). The long streaks of red water south of Cat and Ship islands had virtually disappeared and the patches occurring north of Cat Island were diminished in size. A few streaks of intense water discoloration were observed to the east of Grand Island (Halfmoon Island) and a semicircular patch was noted between Cat Island and Isle au Pitre, Louisiana. By 29 August, only a few patches of red water were sighted north of Cat Island and near Grand Island. Visual observations on 30 August by NMFS personnel aboard the R/V OREGON II indicated that the bloom still persisted in offshore waters in the area of 29°15′ N, 88°40′ W.

No areas of water discoloration were observed on the final survey on 25 September. The heavy seas and winds brought about by Hurricane Frederic (which struck the Mississippi/Alabama coast on 11–12 September) appeared to have completely dissipated the bloom.

The initial outbreak of the *G. monilata* bloom followed a period of lowered salinities in Mississippi Sound due to heavy rains associated with Hurricane Bob (11 July) and Tropical Storm Claudette (23 July). Surface temperatures and salinities during the bloom ranged from 30.0 to 30.8°C and 24.0 to 26.0 ppt, respectively.

Extensive blooms of *G. monilata* occurred in Florida and Alabama concurrent with the Mississippi outbreak. Large areas of discolored water were reported in the Pensacola Bay estuary (William Young, Florida Department of Environmental Regulation [FDER], personal communication) and in lower Mobile Bay and adjacent offshore waters (Walter Tatum, Alabama Department of Natural Resources, personal communication). Personnel of the FDER monitored the bloom in Pensacola Bay from 2 August until 24 August. A maximum cell count of $3.18 \times 10^7$ cells/liter was taken on 15 August. Water temperature was 28.0°C and salinity 14.0 ppt at the time the above sample was collected. Small

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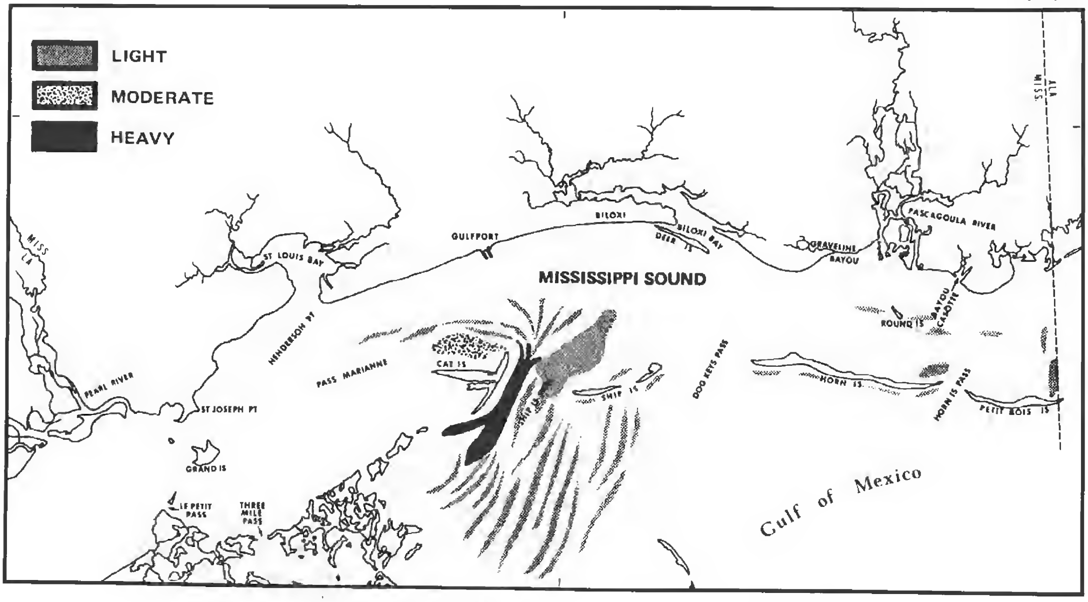


Figure 2. Areal distribution of bloom on 14 August 1979.

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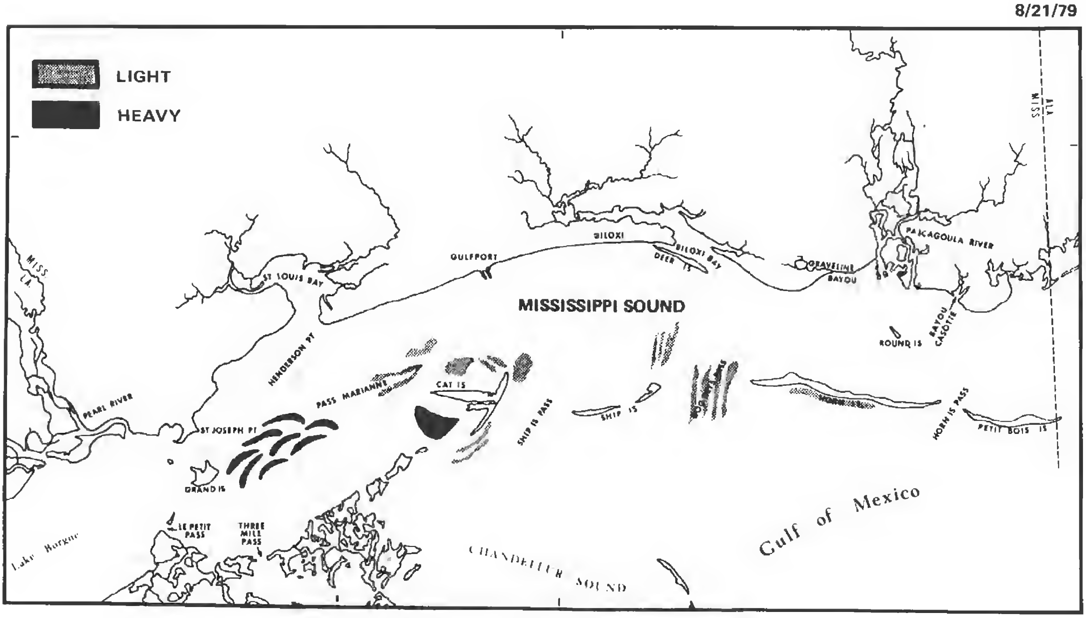


Figure 3. Areal distribution of bloom on 21 August 1979.

fish kills were associated with the bloom in both Florida and Alabama.

A maximum cell count of $1.65 \times 10^7$ cells/liter was made from a dip sample in heavily discolored water southwest of Cat Island, Mississippi, on 22 August. Although our cell counts were high enough to cause death in marine organisms (Wardle et al. 1975), no mortality was observed associated with the bloom in Mississippi. Because the bloom occurred in open waters and was patchy in its distribution, schools of fish evidently were able to avoid it.

ACKNOWLEDGMENTS

The authors thank Dr. R. B. Channel of Vanderbilt University for confirmation of identification of *G. monilata* and Chris Modert of Gulf Coast Research Laboratory (GCRL) who analyzed the plankton samples. For their help in field observations, appreciation is extended to R. M. Overstreet, Kay Richards, Kenneth Melvin, Myron Loman, Thomas Van Devender and James Warren, all of GCRL; to Bennie Rohr of the NMFS, and to the personnel of the Gulf Islands National Seashore, National Park Service.

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